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# Tests of Reinforced Concrete Beams: Effect of Quality of Concrete

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# TESTS OF REINFORCED CONCRETE BEAMS

# EFFECT OF QUALITY OF CONCRETE

BY

EDWIN WILLIAM SANFORD

## THESIS

FOR

## DEGREE OF BACHELOR OF SCIENCE

IN

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U N I V E R S I T Y  O F  I L L I N O I S

May 29, 1906

This is to certify that the following thesis prepared under the direction of Professor A. N. Talbot, Head of the Department of Theoretical and Applied Mechanics, by

EDWIN WILLIAM SANFORD

entitled TESTS OF REINFORCED CONCRETE BEAMS; EFFECT OF QUALITY OF CONCRETE

is hereby approved by me as fulfilling this part of the requirements for the Degree of Bachelor of Science in Civil Engineering.

Ira O. Baker

Head of Department of Civil Engineering

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# TESTS OF REINFORCED CONCRETE BEAMS.

## INTRODUCTION.

Reinforced concrete has come into quite extended use in the last few years for nearly all classes of engineering construction. Concrete itself plays a role as important as does the steel and the variation in strength and elasticity of this material under different conditions has sometimes been overlooked in the design of structures of concrete and steel. The laws governing the combination of concrete and steel although not absolutely fixed, are known with sufficient exactness to permit the design of nearly all classes of structures with the assurance of permanent strength and durability. It is hoped that the results of this thesis will tend to further fix the laws governing the design of reinforced concrete.

This thesis is one one of three various tests of reinforced concrete beams of same materials and is concerning the effect of the quality of the concrete under applied loading at 1/3 points. The materials were furnished by the Joint Committee, appointed by four of the leading American engineering societies, namely, American Society of Civil Engineers, American Society for Testing Materials, Association of Portland Cement Manufacture[5] and American Railway Engineering and Maintenance of Way Association. These tests were conducted in cooperation with the Materials Testing Laboratory of the U.S. Geological Survey, World's Fair Grounds, St. Louis.

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In the use of concrete for engineering purposes a great variety of mixtures and methods of mixingare being used, which in the opinion of the users are undoubtedly the most satisfactory for greatest strength and least cost. The purpose of this thesis is to use a few of the common mixtures and of very lean mixtures to determine their action under loading and also to test specimens of same mixture with different reinforcing bars, different percent reinforcement and with different methods of mixing, to eradicate the faults and increase the strength of the beam. The beams being restricted to a uniform size and one method of loading.

In these tests of beams, it was the purpose to determine the following condition in relation to the specimen tested under one method of loading and of beams of uniform size, (1) The general action of the beam during the progress of the loading and method of its primary and final failure, (2) The deformations and as nearly as possible determine the stresses in the metal reinforcements, the deformation in the concrete and the condition at maximum load carried by the beam, (3) The effect of the amount of reinforcement, (4) The effect of form of reinforcing bar, (5) The position of the neutral axis and the resisting moment of the beam, and to compare these results for beams of same mixtures. In the design of some of the beams it was expected that they would fail by diagonal tension, owing to the lean mixture used; therefore to prevent this, stirrups were placed in a part of the beams outside the load points and the effect of these in preventing diagonal tension noted.

The following sub-division will be made: I. Description of Materials, II. Description of Specimens, III. Description of Tests, IV. Observed Data, V. Discussion of Results, VI. Curves and VII. Tables of original readings.

## DESCRIPTION OF MATERIALS.

In order that the concrete might be more representative of that used in general practice, the materials were purchased in the open market. The care used in mixing and measuring the materials insure a grade of concrete that exists only in the best construction.

STONE: The stone was a good quality of screened limestone from Kankakee, Illinois, ordered to pass a 1 in. screen and to be caught on a 1/4 in. screen. It weighed 85 lb. per cu. ft. loose and contained 43 percent voids. In determination of the proportion of voids in both sand and stone, the material was poured slowly into water so that the voids became filled with water and no air was entangled.

SAND; The sand was of good quality and was screened through a 1/4 in. screen. It contained from ) of clay. It contained 28 percent of voids and weighed 115 lb. per cu. ft. loose. Table gives the average results of mechanical analysis of two samples.

Table. 1 .

MECHANICAL ANALYSIS OF SAND.

| Seive no. | Percent passing. |
|---|---|
| 4 | 100 |
| 10 | 73 |
| 20 | 36 |
| 30 | 12 |
| 74 | 5 |
| 100 | 2 |

CEMENT: The cement used consists of a mixture of five different brands. Table , gives the tensile strength of both neat cement and 1:3 mortar for ages of 7 and 60 days. The briquettes were thumb rammed and were stored in damp air for one day and under water the remainder of the time.

Table 2.

Tensile Strength of Cement.

| Ref. No. | Ultimate Strength, lb. per sq. in. | | | |
|---|---|---|---|---|
| | Age 7 days. | | Age 60 days. | |
| | neat | mortar 1:3 | neat | mortar 1:3 |

CONCRETE: The mixtures used, after careful consideration were considered representative of that used for general construction. The degree of mixing used in actual practice was most desired. A man skilled in making concrete assisted in the work, and great care was taken in the measuring, mixing and tamping to produce concrete as nearly uniform as possible. All the materials were measured by loose volume, one sack cement weighing 95 lb. measured 1 1/8 cu. ft. loose, which was adopted as the unit of measure. The mixing was done with shovels by hand. The sand and cement were first mixed dry, the stone added and the mass mixed until uniform in appearance. A moderately wet concrete was used such that water flushed to surface under

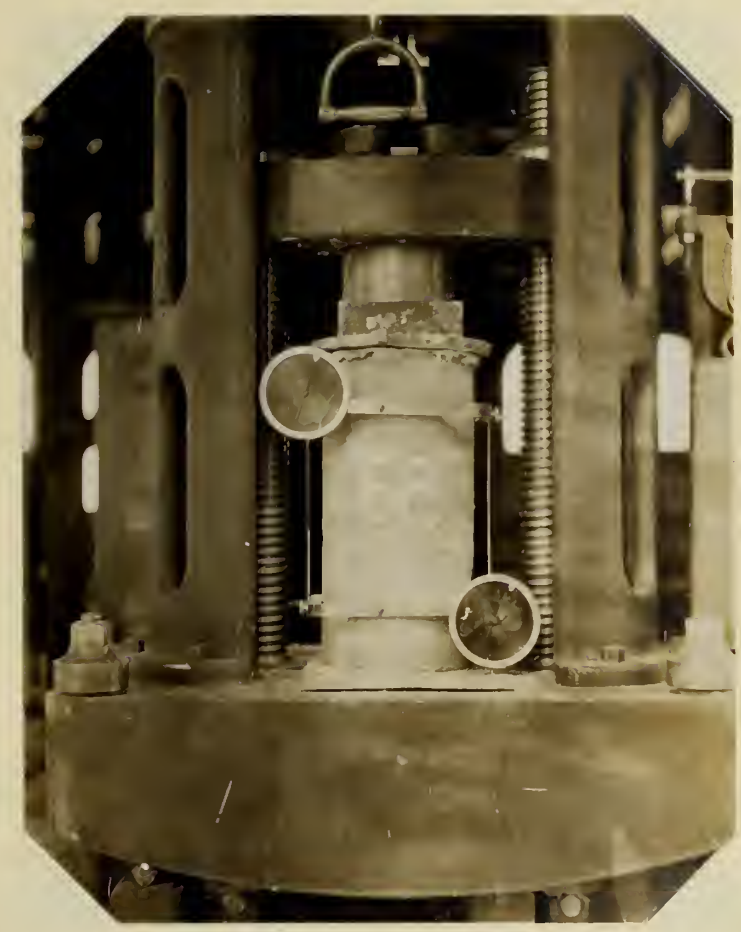
light tamping. Three 6 in. cubes of concrete of same batch as for beam were made from each mixture and stored under wet sand after taking from forms at age of 4 days. Results of cube tests are shown in table . Bond of stone and cement was such as to break the stone when concrete broke in tension. Cubes have same numbers in table as corresponding beam.

RESULTS OF TEST OF 6-IN. CUBES.

| Concrete from Beam No. | Mixture | Max. Load. lb. | Age at test. Days. | Compressive stress lbs.per sq.in. |
|---|---|---|---|---|
| 58 | 1-3-5 1/2 | 45060 | 64 | 1250 |
| 58 | 1-3-5 1/2 | 64930 | 64 | 1800 |
| 58 | 1-3-5 1/2 | 59880 | 64 | 1660 |
| Mean. | | 56620 | | 1580 |
| 60 | 1-3-5 1/2 | 56540 | 65 | 1570 |
| 60 | 1-3-5 1/2 | 64050 | 65 | 1780 |
| 60 | 1-3-5 1/2 | 62390 | 65 | 1730 |
| Mean. | | 60990 | | 1690 |
| 59 | 1-2-4 | 45700 | 64 | 1270 |
| 59 | 1-2-4 | 51880 | 64 | 1440 |
| 59 | 1-2-4 | 50750 | 65 | 1410 |
| 59 | 1-2-4 | 95640 | 65 | 2660 |
| 59 | 1-2-4 | 93220 | 65 | 2590 |
| 59 | 1-2-4 | 101000 | 65 | 2810 |
| Mean. | | 73030 | | 2030 |
| 61 | 1-2-4 | 134000 | 64 | 3730 |
| 61 | 1-2-4 | 121000 | 64 | 3360 |
| 61 | 1-2-4 | 123000 | 64 | 3420 |
| Mean. | | 126000 | | 3500 |
| 65 | 1-3-5 1/2 | 83500 | 59 | 2320 |
| 65 | 1-3-5 1/2 | 85000 | 59 | 2360 |
| 65 | 1-3-5 1/2 | 86050 | 59 | 2390 |
| Mean. | | 84850 | | 2360 |
| 69 | 1-2-4 | 53070 | 59 | 1470 |
| 69 | 1-2-4 | 51230 | 59 | 1420 |
| 69 | 1-2-4 | 59190 | 59 | 1640 |
| Mean. | | 54460 | | 1510 |
| 68 | 1-3-5 1/2 | 74140 | 59 | 2060 |
| 68 | 1-3-5 1/2 | 72640 | 59 | 2020 |
| 68 | 1-3-5 1/2 | 63300 | 59 | 1760 |
| 68 | 1-3-5 1/2 | 63400 | 59 | 1760 |
| 68 | 1-3-5 1/2 | 63800 | 59 | 1770 |
| 68 | 1-3-5 1/2 | 62820 | 59 | 1740 |
| Mean. | | 66680 | | 1850 |

RESULTS OF TEST OF CUBES (CONTINUED)

| Concrete from Beam No. | Mixture | Max. Load. lb. | Age at test. Days. | Compressive stress lb. per sq.in. | |
|---|---|---|---|---|---|
| 70 | 1-3-5 1/2 | 92120 | 58 | 2560 | |
| 70 | 1-3-5 1/2 | 82740 | 58 | 2300 | |
| 70 | 1-3-5 1/2 | 67800 | 58 | 1880 | |
| Mean. | | 80890 | | 2250 | |
| 71 | 1-5-10 | 48700 | 62 | 1350 | |
| 71 | 1-5-10 | 40000 | 62 | 1110 | |
| Mean. | | 44400 | | 1230 | |
| 72 | 1-3-5 1/2 | 63300 | 60 | 1760 | Poorly mx'd. |
| 72 | 1-3-5 1/2 | 57000 | 60 | 1580 | |
| 72 | 1-3-5 1/2 | 71000 | 60 | 1970 | |
| Mean. | | 63770 | | 1770 | |
| Mean. | 1-3-5 1/2 | 70010 | 61 | 1950 | |
| Mean. | 1-2-4 | 84500 | 63 | 2350 | |
| Mean. | 1-5-10 | 44400 | 62 | 1230 | |
| Mean. | 1-3-5 1/2 | 63770 | 60 | 1770 | " " |



Test of Cylinder No. 68

A single cylinder of concrete was made from same batch as the beam for each mixture and stored in air on laboratory floor. Result of tests of cylinders shown in table .

Table 3.

RESULTS OF CYLINDER TESTS.

| Cylinder from Beam No. | Age when Tested. | Mixture | Max. Appl'd Load. | Compressive stress. lb. per sq. in. |
|---|---|---|---|---|
| 58 | 70 | 1-3-5 1/2 | 53000 | 1060 |
| 60 | 70 | 1-3-5 1/2 | 53200 | 1060 |
| 59 | 70 | 1-2-4 | 85000 | 1700 |
| 68 | 63 | 1-3-5 1/2 | 44300 | 885 |
| 70 | 62 | 1-3-5 1/2 | 55000 | 1100 |
| 72 | 60 | 1-3-5 1/2 | 27000 | 540 |
| 73 | 60 | Poorly mixed lin. of top. | 38600 | 770 |

STEEL: The reinforcement used consisted of plain round and Johnson bars.

The plain bars used were 3/4 in. in diameter, with ordinary rolled steel surface. The results of test of plain round bars shown in table .

Table 4.

RESULTS OF TEST OF TENSILE STRENGTH OF STEEL

FOR REINFORCEMENTS.

Plain 3/4 in. Round Bars.

| Steel. From Beam No. | Elastic Limit. | Ultimate Strength. | Percent Elongation in 8 in. | Diam. in in. | Tensile Strength lbs. per sq. in. Elastic limit. | Ultimate Strength. |
|---|---|---|---|---|---|---|
| 58 | 17000 | 27290 | 32 | .750 | 38500 | 61600 |
| 58 | 18770 | 28730 | 27 | .755 | 42000 | 64300 |
| 59 | 18600 | 30630 | 23 | .755 | 41600 | 68500 |
| 59 | 17770 | 27340 | 29 | .750 | 40300 | 62000 |
| 60 | 17450 | 28220 | 28 | .750 | 39600 | 64000 |
| 60 | 17070 | 27380 | 29 | .750 | 38700 | 62000 |
| 61 | 17200 | 25210 | 30 | .754 | 38700 | 56800 |
| 61 | 17300 | 27100 | 31 | .750 | 39200 | 61500 |
| Mean. | | | 30 | | 39820 | 62810 |

The Johnson bar used was 1/2 in. square with actual average area of .25 sq. in. The results of tests of Johnson bars shown below in table .

Table 5.

JOHNSON BARS.

| Steel. From Beam No. | Elastic Limit. lb. | Ultimate Strength. lb. | Per cent. Elongation in 8 in. | Width. in in. | Tensile Strength lb. per sq. in. Elastic Limit. | Ultimate Strength. |
|---|---|---|---|---|---|---|
| 66 | 14300 | 25330 | 14.5 | .50 | 57200 | 101500 |
| 66 | 14640 | 19220 | 17.5 | .50 | 58600 | 77000 |
| 66 | 15100 | 25320 | 16.0 | .50 | 60400 | 101400 |
| 66 | 14800 | 21100 | 16.5 | .50 | 59100 | 84500 |
| 67 | 13800 | 21060 | 17.1 | .50 | 55200 | 84300 |
| 67 | 13840 | 20930 | 18.0 | .50 | 55400 | 83600 |
| 67 | 14100 | 20750 | 17.0 | .50 | 56500 | 83000 |
| Mean. | | | 16.5 | | 57500 | 87900 |

## II. DESCRIPTION OF SPECIMENS.

In carrying out the purpose of this thesis it was considered necessary to investigate the action of the concrete in the following test pieces:

Plain Concrete in Compression: The tests to determine the stress-deformation relation of concrete were made on cylinders 8 inches in diameter and 16 inches long. The forms consisted of two half cylinders cut from wrought iron water pipe, held together by two collars with bolts. Base plated were of cast-iron having a planed top. Also 6-inch cubes were used to obtain the unit compressive stress of the concrete. The forms consisted of two side pieces bolted together with intermediate cross pieces giving the required size of test piece.

Reinforced Concrete Beams: All reinforced concrete beams were restricted to a uniform size and span, being 8 inches wide by 11 inches deep by 13 feet in length, using a span of 12 feet between supports. The amount and kind of reinforcement in each is shown in Table ; the percentage of reinforcement is the ratio of the area of the metal to the area of the concrete above the center of the metal. The metal was placed in a plane 1 inch above the bottom and evenly spaced across the breadth of the beam, the span between the side of the beam and the nearest bar being one-half that between any two consecutive bars. Few of the beams contained stirrups which were made of 1/2-inch plain round bars bent in form of the letter U placed directly below the bars in a vertical position and 1/2 inch from the sides

of the beam, running to 1/2 inch of the top. These stirrups were spaced every 12 inches between load points and supports, using 10 for beams as noted in Table and as shown in figure.

TABLE 6 .

DESCRIPTION OF SPECIMENS.

LOADS APPLIED AT 1/3 POINTS.

| Beam No. | Mixture | Reinforcement Amt. & Kind. | Percent of Metal. | Age at Test. Days. | Remarks. |
|---|---|---|---|---|---|
| 58 | 1-3-5 1/2 | 2-3/4"Plain O | 1.10 | 61 | Rods horizontal. |
| 60 | 1-3-5 1/2 | 2-3/4"Plain O | 1.10 | 61 | " " |
| 59 | 1-2-4 | 2-3/4"Plain O | 1.10 | 62 | " " |
| 61 | 1-2-4 | 2-3/4"Plain O | 1.10 | 61 | " " |
| 62 | 1-5-10 | 2-3/4"Plain O | 1.10 | 62 | " " |
| 63 | 1-5-10 | 2-3/4"Plain O | 1.10 | 61 | " " |
| 64 | 1-3-5 1/2 | 2-3/4"Plain O | 1.10 | 61 | Poorly mixed. Broken in accid'. |
| 65 | 1-3-5 1/2 | 2-3/4"Plain O | 1.10 | 60 | Same as No. 64. |
| 66 | 1-5-10 | 4-1/2"Johnson | 1.25 | 59 | Rods horizontal. |
| 67 | 1-5-10 | 4-1/2"Johnson | 1.25 | 60 | " " |
| 68 | 1-3-5 1/2 | 3-3/4"Plain O 10-1/2"Stirrups, 12" apart | 1.66 | 60 | " " |
| 70 | 1-3-5 1/2 | " | 1.66 | 60 | " " |
| 69 | 1-2-4 | " | 1.66 | 61 | " " |
| 71 | 1-5-10 | " | 1.66 | 60 | " " |
| 72 | 1-3-5 1/2 | 2-3/4"Plain O 10-1/2"Stirrups, 12" apart. | 1.10 | 60 | Poorly mixed. 1" of top. |
| 73 | 1-3-5 1/2 | | 1.10 | 60 | Same as No. 72. |

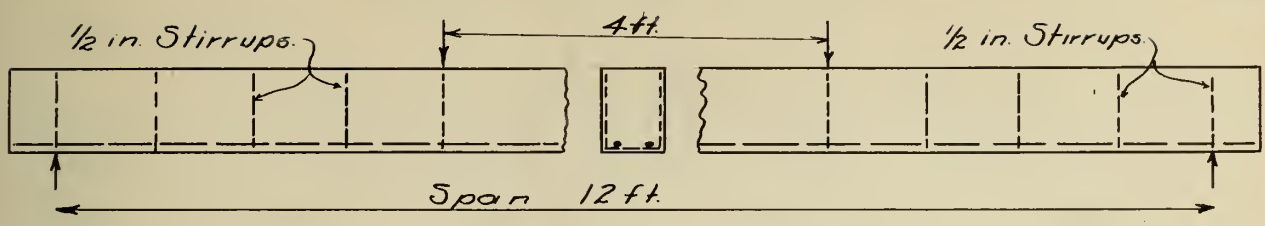
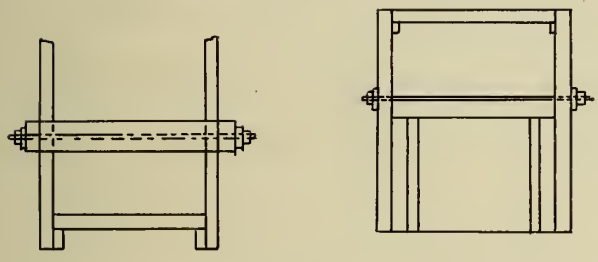



Fig. 1.

Making of Beams: The beams were made directly on the concrete floor of the Laboratory, except that a strip of building paper was spread beneath the forms. Details of forms used are shown in figure . The sides consisted of 2 inch plank dressed on the one surface. The ends were of the same material and were held in place by cleats on the sides. Braces as shown in figure were placed every 4 feet to hold the forms together and to prevent bulging during the tamping of the concrete. The beams were made by placing about a 1-inch layer of concrete of the smaller stones and uniformly distributing these over the bottom of the beam by a wooden template and then placing the reinforcing bars in their correct positions. The beams were then made in layers of 3 in. to 4 in. After each layer had been tamped over, a flat spade was forced between the face of the form and the concrete to produce a better surface and the layer then tamped. No tamping was done in the horizontal plane of the bars lest it should tend to cause a plane of rupture. The upper surface was finished with a thin layer of 1:3 mortar. The beams were numbered consecutively in order of their manufacture and will be referred to by number in the following discussion. In beam No. 64, 65, 72 and 73 concrete was poorly mixed, being turned just one-half as much as

Fig. 2.



ordinarily.

Storage: The temperature of the Laboratory in which the beams were stored ranged between 60°F and 70°F. Nothing was done to protect the surface, such as sprinkling or covering with a damp canvass, but no cracks were found, even in the finished mortar surface, due to shrinkage or rapid evaporation. The general age of a specimen when tested was 60 days, a time sufficient to reduce the effect of the variations to a negligible factor. The forms were not moved for 4 days after mixing. Beams were allowed to remain on the floor for 14 days after which it was necessary to store them in piles of five each, beams supported near end. The exact age of the reinforced beams are given in table 6 .

Steel: In cutting reinforcing bars, the ends of each rod, about 18 inches long were numbered the same as the beam in which they were to be used and reserved for tensile tests of the steel. This was done in order to be sure (in case of wide variation in quality of steel) what kind of steel was in each beam.

## III. DESCRIPTION OF TESTS.

The work up to this time, on the relation of methods of loading on the stress-deformation of concrete in compression and steel in tension, has been chiefly in study of the methods of loading that will approach the actual condition of loading that the beam is subjected in use. The tests were made on the 200,000 lb. Olsen testing machine. The loads were applied continuously and the deformation corresponding to the various loads up to the ultimate strength were determined.

Details of tests.

Plain concrete in compression: In compression tests the top and bottom of cylinders and cubes were coated with a thin layer of plaster of paris to give a uniform bearing, which was allowed to set under a light pressure. A circular plate 1/2 inch thick of cast-iron was placed immediately on top of the plaster of paris and load was applied through a bearing block with an adjustable hemispherical head. For the cylinders the deformations were measured on a gauge length of 10-inches, with Johnson extensometers having special yokes and readings taken for every 10000-lb. to near the maximum and then every 5000-lb. Cylinders and cubes were tested to destruction on 100,000-lb. Reihle testing machine, using the slowest speed of the machine.

Beams: The beams weighed about 1200 lb. each and were easily moved to and from the machine by means of a portable trestle crane provided with two hoists and trolleys running on an overhead track-way. They were run along the table of the machine on a dolly and lifted into place on the supports by pulleys suspended from the ceiling. The tests were made on the 200,000-lb. Olsen testing Machine.

Span and Loading: The span and loading was in all cases the same, the span being 12 feet and the load applied at one-third points. General arrangement of loading may be seen in the photograph. The load was applied by the machine at the middle of a 10-inch I-Beam. The I-Beam transmitted it to the beam through two steel rollers, 2 inches in diameter placed at

the one-third points of the span length. The supports at the end of the span rested on the table of the machine. The tops of these supports have curves of small radius; the bases are curved to a 12 inch radius, thus permitting any change in length of the lower surface of the beam without throwing any additional longitudinal stress on the beam. Bearing plates 3/8 in x 3 in x 12 in were placed above the beam at the points of application of the load and below it at the supports. A layer of plaster of paris was put between the bearing plates and the beam and allowed to set under such weight as came upon them from the manner of loading. A plate 1/2 in. x 4 in. x 12 in. was placed between the head of the machine and over the I-Beam at the center of the beam.

Loads: The loads were applied by the slowest speed of the machine, with the advance of head of machine of .04 in. per second. The readings were taken at intervals of 1000-lb. Sometime after maximum was reached the machine was placed on a faster speed and a few readings taken at the even 1000-lb. loads.

Deflections at Center. Deflection at center were recorded at every reading of extensometer as a check on the more general characteristics of the loads-deformation diagram. The readings were obtained by means of a fine thread stretched at a constant tension between points at the middle of the effective depth of the beam over the supports and passing in front of a paper scale attached on the side of the beam at the middle of the span. The scale was pasted on the face of a mirror. These readings were taken to 1/64 inches.

Deformation: To obtain the deformation in the various fibers of the beam the device shown in the accompanying photo-

graphs was used. Two yokes were attached to the beam 4 inches outside of the load points by 2 pair of screws provided with lock nuts to allow adjustment. The upper pair of contact points was placed 1/2-inch below top of the beam and the lower pair 9 1/2 inches below the upper. These contact points are adjustable. The rollers and dials were of Johnson extensometer type, so attached that the middle of the rollers was directly in the line of contact points and axis of rollers at right angles to sides of the beam. The rollers were 20 1/4 in. apart vertically, the upper one being 5 1/2 in. above the upper contact points. Each division of dial indicated 0.001-inch and with vernier read to .0001 in. The second yoke was provided with fixed points in positions corresponding to the position of the four rollers. The motion of each roller relative to the corresponding fixed point on the second yoke was obtained by using a steel strip 12 in. long resting on the brass roller and rigidly fastened to a 5 feet length of 3/8 inch brass pipe. At the other end of this pipe, a V-shaped notch was cut, which fitted the support of the second yoke.

General features: Three observers were present during each test and one to regulate the application of the load, two to read the deflections at centers and extensometers. The extensometers were removed shortly after maximum load was reached, the loading being continued until crushing began at the top surface, and then faster speed was put on.

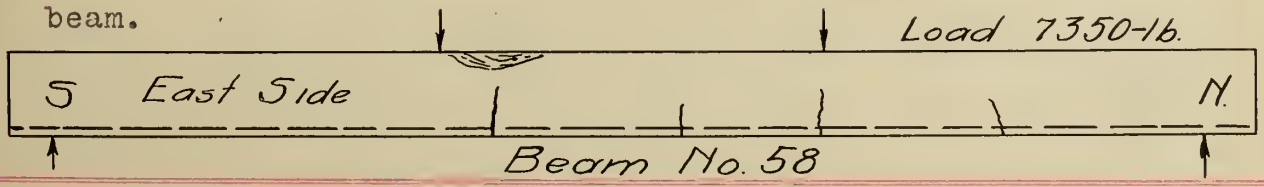
## IV. OBSERVED DATA.

In testing the beams for this thesis, careful attention was paid to the action of the beam under loading, all cracks were noted at the maximum load. Careful watch was kept for signs of compression. The load was continued after maximum and action of beam was noted. All beams were loaded at 1/3 points and span was 12 feet. The data taken during each test for each beam is as follows:

### Beam No. 58.

1.10% reinforcement, 2-3/4 inch plain round bars; mixture, 1-3-5 1/2. Weight of Beam 1200 lb., with apparatus 1460 lb.

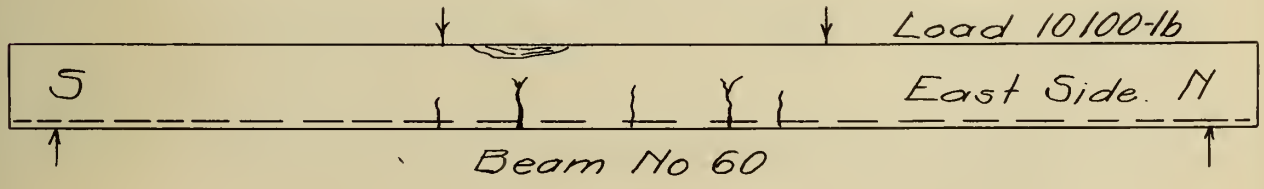
In testing beam no cracks were observed until load of 5000 lb. was reached. Cracks appeared from then on and at load of 9000 lb. cracks every 6 inches for 4 feet on each side of middle. Max. load was reached at 9860 lb. and cracks were as follows: at 1 foot- 5 inches S of C, 1/64 in. x 4 in.; and 3 ft. 10 in., 1/100 in. x 4 in. ; 2 ft. 0 in., 5 in.; 6 in., 4 in. all north of C. All other cracks very small. On continuing load from maximum for about 4 min. and at load of 9400 lb. compression began at 1 ft. 5 in. S of C, crack below 1/16 in. x 5 1/4 in. Load dropped off slowly after maximum, deflection at 9400 lb. was 1.09 in. at middle. At load of 7350 lb. crushing for distance 1 ft. 4 in.; crack 3/32 in. x 5 1/4 in. Beam failed by tension. Cracks were very similar on both sides of beam.



Beam No. 60.

Beam same as No. 58. Weight of beam 1210 lb., with apparatus 1460 lb.

In testing beam first crack appeared at load of 4500-lb and from then on cracks appeared slowly and at load of 7000-lb. cracks were opened every 6 in. between 3 ft. N of C and 4 ft. S of C. Maximum load was reached at load of 10360 lb; deflection at center 11/32 in. Cracks were as follows, 1 ft. 6 in. N of C 1/50 x 4 in. at middle 1/100 x 5 in. and 1 ft. 2 in., 1/40 in x 5 in.; 2 ft. 1 in. , 1/100 in x 3 1/2 in. all south of center. All other cracks very small and extending up on beam about 2-in. Crack about the same on both sides. On continuing load after maximum for about 9 min. and at load of 10100 lb., compression began at 1 ft. 2 in. S of C. deflection at middle 1.3 in., crack below 3/16 in. x 6 1/2 in. Cracks opened up at 1 ft. N of C to 1/16 in. x 5 1/2 in. Load held up well after maximum until load of 9000-lb. was reached and then decreased more rapidly. Beam failed by tension.

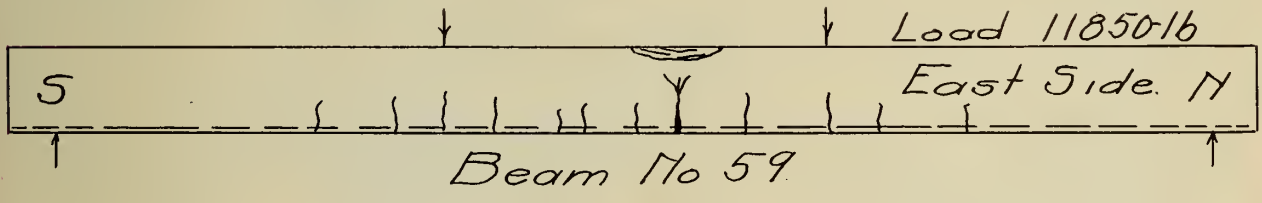



Beam No. 59.

1.10% reinforcement, 2 3/4 in. plain round bars, mixture 1-2-4, Weight of beam 1200 lb, with apparatus, 1460 lb.

In testing this beam no cracks were observed until load of 5000 lb. was reached. Cracks appeared from then on and at load of 8000 lb. crack about every 6in.for 3ft. 6in. on

each side of middle, at 9000 lb. cracks extend up 4 1/2-in on beam. Maximum was reached at load of 12000 lb. when cracks were as follows 3 ft. 4 in., 4 in; 2 ft. 6 in. 1/100 in. x 4 in; 2 ft. 1/100 in x 5 in.; 1 ft. 2 in. 1/200 in. x 4 1/2 in.; 6 in. 1/50 in. x 6 in. all N of C at center 1/200 in. x 4 in. Cracks S of middle, 6 in. 1/200 in. x 4 in.; 10 in. , 3 in.; 1 ft. 6 in. 1/100 in. x 4 in. ; 2 ft. 1/100 in. x 5 in.; 2 ft. 6 in. 1/100 in. x 4 1/2 in. 3 ft. 4 in. 4 in. All other cracks were very small and about same on both sides of beam. In applying load after maximum for about 7 min, until load of 11850 lb. was reached, compression began at 6 in. N. of C., cracks below being 1/8 in. x 7 in, crack at load point also observed up to 1/20 x 5 in. Deflection at center 19/32 in. Load held up well until beginning of compression. Beam failed by tension.

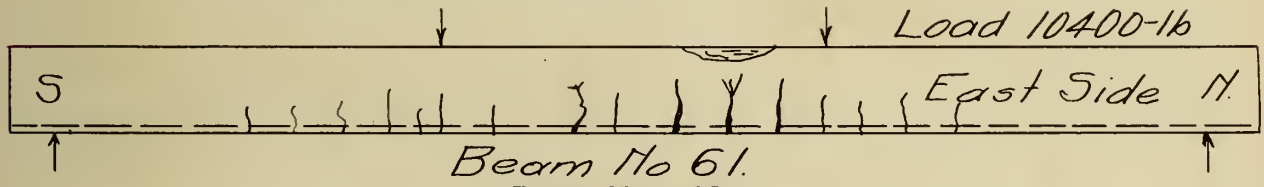



Beam No. 61.

Beam same as Beam No. 59. Weight of Beam 1180 lb. with apparatus, 1430 lb.

In testing this beam no cracks were observed until load of 5000 lb. was reached. Cracks appeared from then on, when at 9000 lb. were about every 6 in. between 4 ft. S of C and 3 ft. N of C. Max. load was reached at load of 10960 lb., when cracks were as follows, 3 ft. 4 in.,3 in; 2 ft. 8 in., 5 in.; 2 ft. 4 in.,4 in.; 2 ft.,4 1/2 in.; 1 ft. 7 in. 1/200 x 4 in., 1 ft., 1/40 in. x 5 in., 6 in., 1/200 in. x 4 1/2 in. all north of middle. South of Middle, 3 in, 4 1/2 in.; 1 ft.

6 in., 3 in.; ; 2 ft., 4 1/2 in.; 2 ft. 3 in., 3 in.; 2 ft. 6 in. 1/100 in x 4 1/2 in.; 3 ft., 3 1/2 in.;4ft. and 3 ft. 6 in., 3 in. Load held up well after maximum. On applying load after maximum when at load of 10400 lb.; compression began at 1 ft. N of C, deflection at center 1 5/32 in. Cracks were as follows, 1 ft. N of C 3/16 in. x 6 1/2 in.; 6 in. N of C 1/8 in. x 7 in., 7 1/2 in. S of C, 1/8 in. x 6 1/2 in., 1 ft 7 in. N of C, 3/32 in. x 6 in. Crack 1 ft. N of C open up first and then quite rapidly cracks, 6 in. and 1 ft. 7 in. N of C and 7 1/2 in. S of C. Other cracks did not open up further after maximum. Load held up to 10250 lb at the last, deflection at this load, 2. in. Beam failed by tension.

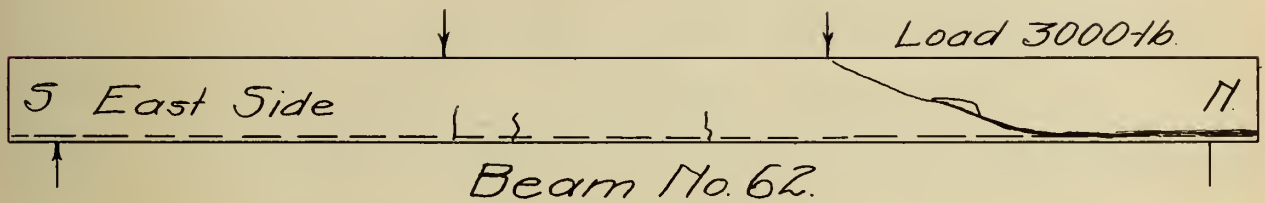



Beam No. 62.

1.10% reinforcement, 2 3/4-in. plain round bars, mixture 1-5-10, weight of beam 1250 lb., with apparatus 1520 lb.

In testing this beam no cracks were observed until load of 4000 lb. was reached. Cracks appeared from then on when at 7000 lb. there were cracks about every 10 in. between 5 ft. N of C and 3 ft. S of C and as follows: 10 in., 1/100 in. x 4 in. N of C;S of C, 1 ft. 3 in., 1/100 in. x 3 1/2 in., 1 ft. 11 in. 1/200 in. x 3 1/2 in., all othercracks were very small. At 8600 lb. began shearing at 4 ft. North of Center, at angle of 60 degrees, crack 1/40 in x 4 1/2 in. Maximum load was reached at load of 8850-lb. cracks have not opened up since 7000 lb. load. Shear increased at N end, load dropped then

to 7100 lb, but on continuing of load beam picked up to 8400-lb. and then failed suddenly, load dropped to 3000-lb. Beam failed by shearing along top of beam from 4 ft. N of C to end. All stones at break are on upper surface of and cement on lower. Beam failed by diagonal tension.

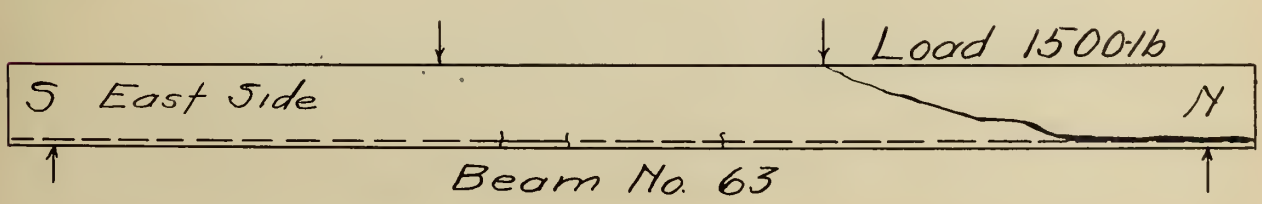



Beam No. 62.

Beam No. 63.

Beam same as Beam No. 62. Weight of beam 1170 lb. with apparatus 1470 lb.

In testing this beam first crack was observed when load of 6000 lb. was reached. Cracks appeared from then on, when at load of 7000 lb. cracks were about every 12 in. for 3 ft. on each side of middle. Maximum load was reached at 7360 lb. and dropped immediately. All cracks except at failure very small running up 2 in. on beam. Failure caused by shearing along top of bars at point 4 ft. 6 in. N of C to end of beam. Load dropped after maximum at 1500-lb. and held there. At load of 1500 lb cracks at failure 1/4 in. wide along beam, running up to N load point. Failure same on both sides of beam. Appearance of rupture same as for beam No. 62. Beam failed by diagonal tension.

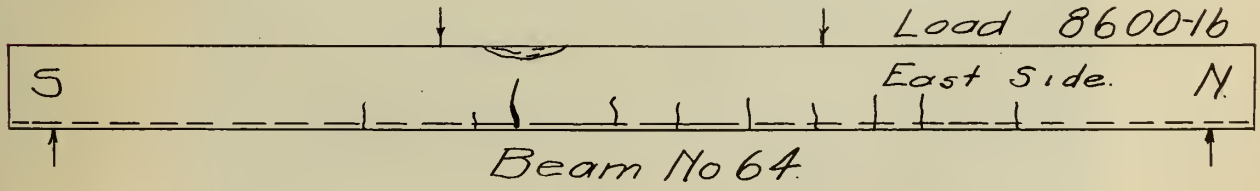



Beam No. 63

Beam No. 64.

1.10% reinforcement, 2 3/4-in. plain round bars. Concrete 1-3-5 1/2 poorly mixed, weight of beam 1220 lb., with apparatus 1425 lb.

In testing this beam no cracks were observed until load of 4000 lb. was reached. Cracks appeared from then on when at load of 9000 lb. cracks were about every 6 in. for 2 ft. on S of C and 4 ft. N of C. Maximum load was reached at 9850 lb. appearance of cracks as follows: 4 ft. 0 in., 3 in; 3 ft, 0 in., 4 in.; 2 ft. 6 in., 4 in.; 1 ft. 10 in., 1/100 in. x 3 in.; 1 ft. 2 in., 1/70 in. x 4 in.; 6 in., 3 in. all north of middle. South of middle; 2 in, 1/100 in. x 4 in.; 1 ft. 3 in 1/200 in. x 3 1/2 in.; 1 ft. 8 in., 2 in.; 2 ft. 10 in., 3 1/2 in. Cracks on west side of beam not over 3-in high. Other cracks very small. Load dropped off after maximum to 9000-lb. On applying load after maximum for sometime, compression began at 1 ft. S of C. Crack below 3/16 in. x 6 1/2 in. at load of 9300 lb. Other cracks unchanged. Load held up to 8600 lb. at last with deflection of 1.84 in. at center. Beam failed by tension.




Beam No. 65.

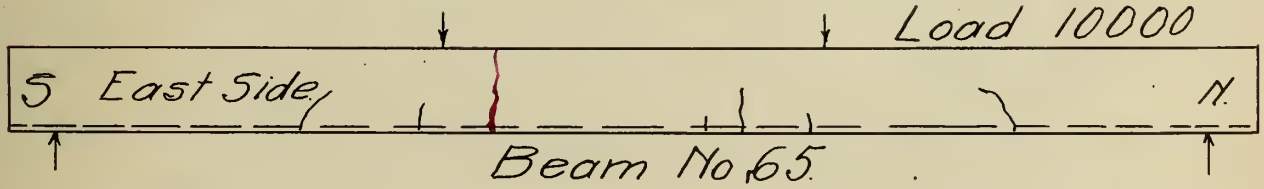
Beam same as Beam No. 64. Weight of beam 1340 lb. With apparatus 1600 lbs. The beam was injured in an accident which caused a crack across beam at 1 ft. 5 in. S of C. Crack

Failure of Beam No64.

Failure of Beam No65

is visible except at lower west side of beam for 3 in. from corner.

In testing of beam fissure was noticed to open up at load of 2000lb. to 1/100 in. and at 3000opened entirely across bottom and up on side of beam and other cracks began to appear at this time and at load of 9000 lb cracks were about every 6 in. between load points. Fissure opened to 1/16 in. wide. Maximum load was reached at 10000 lb., fissure 5/64 in. wide. Other cracks as follows: 1 ft. 2 in., 1/100 in. x 5 1/4 in.; 1 ft. 10 in. 1/200 in x 2 in., 8 in. 1/100 in. x 2 1/2 in. all N of C., 2 ft. 4 in. S of C, 1/100 in. 5 1/4 in. All other cracks very small not running up on side. Cracks same on both sides. Load dropped to 9800 lb. after maximum. On continuing load it picked up to maximum and remained here for some time, when at 10000 lb, beginning of compression is noticed above fissure, which is 3/32 in. wide at bottom of beam. Diagonal tension also started at 4 ft. N of C at angle of 50 degrees. 6 in. high and at 3 ft. 6 in. S of C at angle of 50 degrees and 5 in high. Cracks small, crack at 2 ft. 9 in. N of C opened to 1/40 in. x 5 1/2 in. after beginning of compression. Load drops off slowly. Other cracks remain the same. Beam failed by tension.




Beam No. 65.

Beam No. 66.

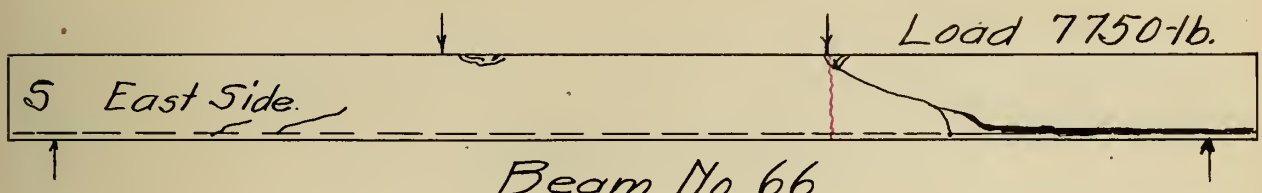
1.25% reinforcement, 4 1/2-in. Johnson bars, mixture 1-5-10. Weight of Beam 1200 lb., with apparatus 1440 lb.

This beam was injured in an accident, which caused a crack across top of beam 2 ft. 1/2 in. N. of C. and extending down sides of beam 6 1/2 in. from top and very small.

In testing this beam no cracks were observed until a load of 6000 lb. was reached. Cracks appeared from then on, fissure extended to bottom of beam, when at load of 7000 lb. cracks about every foot, for 4 ft on each side of center. Maximum load was reached at 8000 lb. crack at 2 ft. 8 in. N of C, diagonal tension started at 3 ft. 3 in. and at 3 ft. 6 in. N of C, at 3 ft. 3 in. crack at angle of 60 degrees and about 4 1/2 in. high at 3 ft. 6 in. crack irregular, running up at angle of 45 degrees and 5 1/2 in. high, crack extended along top of reinforcements from 3-ft. 6-in. to 4-ft. 4-in. N of C, 1/16 in. wide. These cracks join at about 4 1/2 in. up on beam. Diagonal tension cracks also at 3 ft. 8 in. S of C at an angle of 15 degrees extends to height of 4 1/4 in. crack began at 1 in. from bottom of beam, a small crack also observed at 4 ft. 3 in. S of C running up from 1 in. to 2 1/4 in. high and 5 in. length. Compression began at 1 ft. 6 in. S of C at same time as cracks at 3 ft. 8 in. were observed. Load dropped to 7250 lb. after maximum and upon continuing load for about 1 min. with an additional deflection of 1/10-in. the beam droped suddenly at load of 7750 lb. due to the shearing along top of reinforcements from 4-ft. 4-in. N of C to end on west side and just above on east side. Other cracks do not change from maximum. Stone is observed to be on upper side of crack and cement at lower side. Beam failed by diagonal tension.

Failure of Beam No66.

Failure of Beam No67.



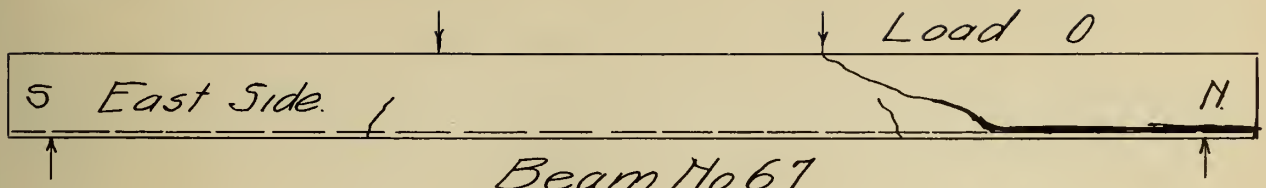

Beam No 66.

Beam No. 67.

Beam same as No. 66. Weight of Beam 1200-lb., with apparatus 1450 lb.

In testing this beam no cracks were observed until load of 6000-lb. was reached. Cracks appeared from then on when at load of 7000 lb. cracks about every 10 in. and following cracks, 3 ft. 8 in. N of C, diagonal crack at angle 40 degrees, 3 in. high on west side about 4 1/2 in. long from top of reinforcement . At 2 ft. 9 in. N of C, diagonal crack at angle of 55 degrees toward N load point., 5 in. high and about 1 3/4 in on west side. At 2 ft. 9 in. S of C diagonal crack at angle of 50 degrees 4 3/4 in. high at west side is 2 ft. 6 in. S of C and 3 1/2 in. high and nearly vertical toward load point. Other cracks only up 2 in. high and very small as the diagonal cracks. Maximum load was reached at 7850 lb. about 2 minutes after continuing load from 7000 lb. The load dropped to 6350 lb. after 7000 lb. was reached and on continuing load reached 7850 lb. Beam droped suddenly from maximum. Just before maximum, a crack was observed to extend along reinforcement. from 3 ft. 8 in. to 4ft. 6in. N of C and crack was about 1/40 in. wide. The appearance of rupture shows that the concrete sheared off above the bars for 1 ft. 6 in. from N end of beam. Imprint of bars perfect at 1 ft. 8 in. from N end. Beam failed by diagonal ten-

sion.

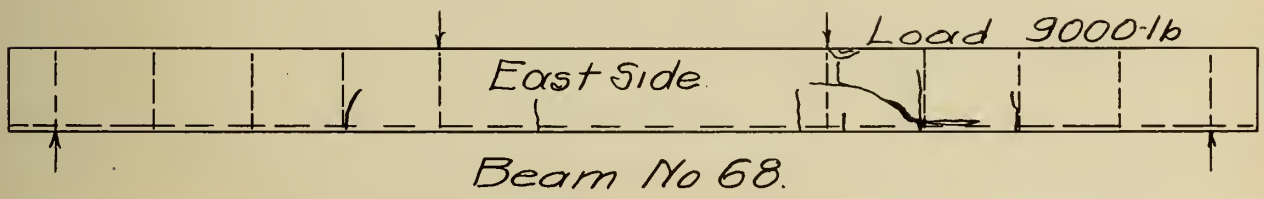



Beam No. 68.

1.66% reinforcements. 3 3/4-in. plain round bars. 10 1/2-in. stirrups 12-in. apart. Mixture 1-3-5 1/2. Weight of beam 1220-lb. with apparatus, 1490-lb.

In testing beam,no cracks were observed until load of 5000 -lb. was reached. Cracks appeared from then on when at load of 10000lb. cracks were about every 6 in. for 3 ft. on each side of center. When at load of 13000 lb. diagonal crack at 3 ft. 0 in. N of C at angle of 45 degrees and 4 1/4-in. high also at 3 ft. S of C running up beam 4 in. and then at angle of 45 degrees, 7 in. high. Maximum load was reached at 14220 lb. Crack 3 ft. N of C extended to under the load, 1/32 in. wide, and 1 ft. 8 in., 5 in. high, 2 ft. 2 in., 2 In. all N of C. 1 ft. 0 in., 4 in., 2 ft. 0 in., 3 in. all S of C. 3 ft. S of C diagonal crack not changed from 13000 lb. load, 1/50 in. wide. All other cracks about 1 in. up on beam. Load at maximum dropped to 12650 lb. and on continuing load picked up immediately. Crack extended along beam 6 in. N of 3 ft. N of C along top of beam at 13000-lb load after maximum.At 13000 lb. beginnging of compression, 1 ft. 8 in. N of C. Crack at 3-ft. N of C extended 1 in. inside load point, at 10000 lb. crack runs up 8in. along stirrup at 3 ft. N of C. 8000 lb, crack run up 4 in. along stirrup at 4 ft. N of C. Load decreased slowly

from maximum, holding up to 6000 lb. at last. At load of 9000 lb. beginning of compression 2 ft. 2 in. N of C. Then diagonal cracks opened up large enough to see into it, the concrete was noticed to be cracked above bar. After maximum a slipping sound was heard and the underside of bar was smooth showing slipping of bars at stirrup 3 ft. N of C. Stirrups slipped a very little at the last. Stirrup sagged at center. Splitting along bars extended from 3 ft. to 3 ft. 8 in. N of C. Deflection at 4000 lb. was 4 1/2 in. at center. Beam failed by diagonal tension.



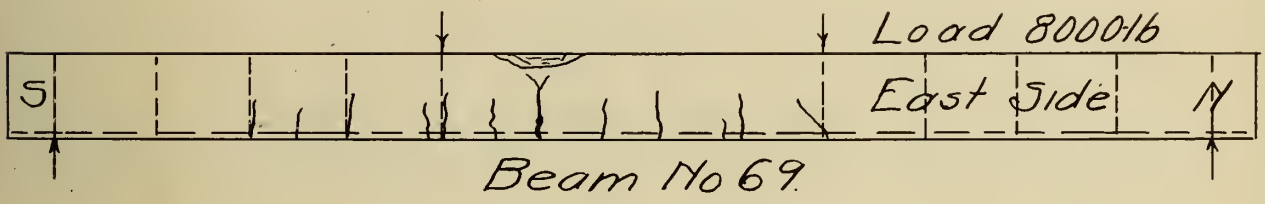

Beam No 68.

Beam No. 69.

1.66% reinforcement. 3 3/4 in. plain round bars, 10-1/2 in. stirrups 12 in. apart, mixture 1-2-4. Weight of beam 1230 lb.; with apparatus 1490 lb.

In testing this beam, no cracks were observed until load of 6000-lb. was reached; cracks appeared from then on, when at load of 10000-lb, cracks were about every 6-in. for 4 ft. each side of middle of beam. Maximum load was reached at 16000-lb. and cracks were as follows 2 ft. 0 in., 4 in., at angle of 60 degrees toward C., 1 ft. 2 in., 5 3/4 in.; 4 in., 5 1/4 in.; 1 ft. 7 in., all N of C; 4 in., 4 3/4 in.; 1 ft. 0 in., 4 in.; 1 ft. 6 in. 4 3/4 in.; 2 ft. 0 in., 5 1/4 in.; 2 ft. 4 in., 3 1/2 in.; 3 ft. 0 in., 5 1/4 in. high at center of stirrup. 3 ft. 6 in., 3 3/4 in. and 4 ft. 0 in., 3 3/4 in. along stirrup, all S of Center. All cracks above 4 in. high about 1/100 in.

wide, other cracks are only on bottom. Load dropped off to 15000-lb. and on continuing load picked up to 15700-lb., at 15300-lb. beginning of compression at top 1 ft.2 in. S of C, crack below 3/32 in x 7 in. Load decreased very slowly from maximum and held 8000 at last. Most of cracks symetrical about center. This beam showed a very good appearence and showed very few open holes. Beam failed by tension.

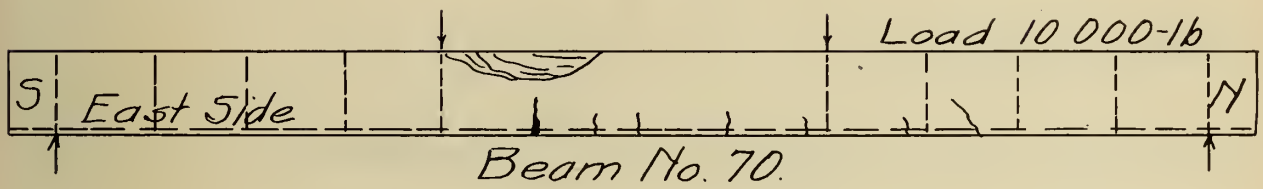



Beam No. 70.

1.66% Reinforcement. 3-3/4-in. plain round bars, 101/2-in. stirrups 12-in. apart, mixture 1-3-5 1/2. Weight of beam 1200 lb. with apparatus 1420 lb.

In testing this beam no cracks were observed until a load of 4000 was reached. Cracks appeared from then on when at load of 11000 lb. cracks every 6 in. for 4 ft. on each side of the middle. Maximum load was reached at 13710 lb. beginning of crushing on top at 1 ft. 2 in. S of C., cracks as follows: 3 ft. 6 in. at angle of 60 degrees, 4 1/2 in. high; 2 ft. 8 in. 2 in.,; 2 ft. 0 in., 4 in; 1 ft. 8 in., 2 1/2 in; 1 ft. 0 in. 3 in.; 0 ft, 1 in. 3 in. all N of C; Oft. 5 in., 2 1/2 in.; 1 ft. 0 in. 2 1/2 in; 2 ft. 0 in., 3 1/4 in. all S of C. Above cracks very small. Load dropped to 12350-lb. after maximum, on continuing picked up to 13500 lb. At 12000 lb. crack 1 ft. 0 in S of C. 3/32 in. x 4 in., crushihg appears rapidly and extends

from center to S load point at 10000 lb. 1 ft. S of C not increased in height but 1/8 in. wide. All cracks directly across beam. Load holds up well after maximum. Beam failed by compression.



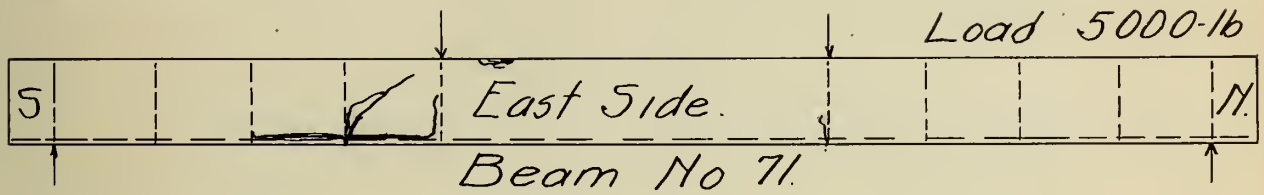

Beam No. 70.

Beam No. 71.

1.66% reinforcements. 3-3/4-in. plain round bars, 10-1/2-in. stirrups 12-in. apart. Mixture 1-5-10. Weight of be beam 1200-lb., with apparatus 1460 lb. Great % of sides of beam open holes.

In testing this beam no cracks were observed until a load of 3000-lb. was reached. Cracks appeared from then on when at load of 7000 lb., cracks every 12 in. for 3 ft. from center. Maximum load was reached at load of 7600 lb. and dropped to 6600-lb. Cracks are as follows: 2 ft. 0 in. N of C, 3 in at 3 ft. 0 in. S of C 1/32 in. x 6 in. at angle of 60 degrees. All other cracks only visible on lower side of beam. On continuing load and at 6000 lb. crack at 3 ft. S of C extended 7 1/4 in. high, crack also started at 2 ft. 10 in. S of C joins crack from 3 ft. 0 in. S of C vertically above it., at 5000 lb. beginning of crushing at top 1 ft. 7 in. S of C, crack at 3 ft. 0 in. S of C 1/16 in. wide by 7 3/4 in. high. Splitting along bars to 4 ft. S of C. Load dropped off rapidly and diagonal crack opened rapidly at 4000 lb. splitting N along bar to 2 ft. S of C. Loading holds up well after 5000 lb. Crack ex-

tended N to 2-ft. S of C and then runs up vertically 5 1/4-in. and is about 1/32-in. wide. Bars pull up from stirrup after maximum. Bars plainly observed to slip. Beam failed by diagonal tension.

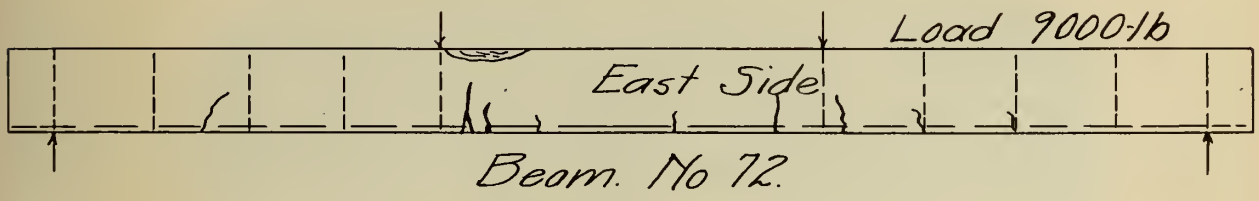



Beam No. 72.

1.10% reinforcements. 2-3/4-in. plain round bars, 10 1/2 in. stirrups 12 in. apart. Mixture 1-3-5 1/2, poorly mixed with 1 in. of top. Weight of beam 1170 lb., with apparatus 1430 lb.

In testing this beam no cracks were observed until load of 4000 lb. was reached. Cracks appeared from then on and when at load of 7000 cracks were about every 6 in. for 3 ft. on each side of center. Maximum load was reached at 10270-lb. when cracks were as follows: 4 ft. 0 in., 2 in.; 3 ft. 0 in., 3 in.; 2 ft. 4 in., 1/50 in x 5 in.; 1 ft. 6 in., 1/50 in. x 5 in.; and 0 ft. 5 in., 3 in. all N of C; 1 ft. 0 in., 2 in., 1 ft. 6 in., 3 1/4 in., 1 ft. 8 in., 1/50 in. x 6 in.; 2 ft. 4 in., 1/50 in. x 4 in., 4 ft. 6 in., 1/100 in. x 5 in. all S of C. Load dropped to 9000 lb. at maximum picked up on continuing load to 10000 lb. Diagonal cracks started at 3 ft. N of C at angle of 45°, 3 in. high at 4 ft. S of C, Angle 45° and 5 1/2 in. high, running up along center of stirrup for 2 in. Load holds up well after maximum. Cracks 1 ft. 6 in. S of C opened up at load of 9400 lb. to 1/16 in. wide. At 9530, crushing begins at 1 ft. 5 in. S of C, cracks 1 ft. 8 in.S of C, 1/16 in. x 6 1/2

running up toward point of compression at angle of 50° and is at 1 ft. 10 in. S of C on west side. Beam failed by tension.




Beam. No 72.

Beam No. 73.

Beam same as No. 72. Weight of beam 1210 lb. With apparatus 1440 lb.

In testing this beam no cracks were observed until load of 4000 lb. was reached. Cracks appeared from then on andwhen at load of 8000 lb. were about every 6 in. for 4 ft. N of C and 3 ft. S of C. Maximum load was reached at 9900 lb. Cracks were as follows: 4 ft. 0 in. 2 1/2 in., 2 ft. 0 in., 2 in., 1 ft. 6 ih. 3 1/4 in.; 0 ft. 10 in. 3 in., and 0 ft. 2 in. 3 in. all N of C; 0 ft. 10 in. 5 in., 2 ft. 0 in. 5 1/2 in., 2 ft. 6 in. 3 1/2 in., 3 ft. 0 in. 4 1/2 in., at angle of 85 degrees, all S of C. All of above cracks are of same size about 1/100-in. wide. All other cracks not appeared on side. Load dropped to 8640-lb. on continuing load picked up to 9570-lb. At 9350-lb. crushing appears at top, 1 ft. 0 in. S of C., crack 10 in. S of C 1/32 in. x 6 in. All other cracks are the same. At 9400 lb. crack 1 ft. 11 in. S of C 1/16 in. x 6 1/2 in. crack is vertical for 4 3/4 in. then at angle of 45 degress; at 9000, 1 ft. 5 in. S of C, 1/32 in x 5 1/4 in. Load held at 7000 lb. at the last, crack 1 ft. 4 in. S of C 1/8 in. wide; other cracks not noticeable. Load dropped off slowly. Beam failed by tension.

Beam No 73

Failure of Beam No. 73.

Broken Beams.

## DISCUSSION AND CONCLUSION.

In the discussion of the results of the tests of the beams it is the author's intention to compare them according to the mixture of the concrete and to give his conclusion concerning each mixture and then to give a general summary of all the tests.

MIXTURE 1-5-10.

In the twin Beams No. 62 and 63 having 2-3/4-in. plain round bars, 1.10 % reinforcement, the maximum loads differed considerably. The points of failure of both beams are within 6 in. of the same part of the beam and in the weaker beam, the failure was 6 in. nearer the support, which would cause the difference in strength as the shearing area above the bars is less. This difference is probably due to a defective place in the concrete. The failure crack ran toward the load point in both cases.

The deformations in the steel and upper fiber agree very well until load of 7000-lb. is reached and then in Beam No. 62, the deformation of the steel increase less rapidly and at 8000-lb. remains constant and upper fiber increase more rapidly, which is probably due to the opening of the diagonal crack thus throwing the compression on a smaller area producing a greater deformation in the concrete and the bending at the center gradually decreased. The stresses as computed from the resisting moment and that necessary to give the unit deformation in the steel at maximum agree very well, showing that there was no slipping of the bars. In Beam No. 63, the deflection at the

center was greater for the maximum load than for Beam No. 62, which was probably due to holding the load for about 4-5 minutes at 7000 lb. and that the diagonal tension cracks had appeared and opened up, causing the load to decrease and upon continuing load, until enough of the tension carried by the concrete was thrown into shear above the bars to cause sudden failure, while in Beam No. 63 load was applied steadily at the maximum, which shows that non-uniformly applied load near the maximum promotes an early failure. The compressive stress in the concrete due to bending does not exceed the ultimate compressive stress of cubes at maximum load. The position of the neutral axis is higher in the weaker beam, due probably to a variation in the concrete causing an increased deformation in it.

In Beam No. 66 and 67, the reinforcement were changed to 4-1/2-in. Johnson bars. The maximum loads agree very well, but with the use of the corrugated bars there is not any noticeable increase in the strength of the beam, which shows increase in bond and amount of reinforcement, in no way eliminates the diagonal tension. The deformation of the upper fiber of Beam No. 66 increases more rapidly with the same increase of load than No. 67, which is in part probably due to the breaking of beam by accident and to the position of diagonal tension cracks throwing the compressive stress upon a smaller area,
for in Beam No. 66, cracks appeared at ends of beam, and also signs of compression appeared at maximum. In Beam No. 67 the diagonal tension cracks are more nearly perpendicular and that they therefore do not increase the compression as much as those

more inclined. It was observed that in these failures the rods pulled away from the concrete for about a foot from crack toward support, then sheared off along the top of thebars, causing a sudden failure of beam. This splitting along the top of the bars is due to the effect of a cantilever action set up on the portion of the beam inside of diagonal tension crack, throwing the load that comes upon it into the bars, and they in turn tending to adjust themselves, tend to pull away from the concrete, causing concrete to split along the surface of the reinforcement until the area carrying the horizontal shear is decreased until it is unable to hold, thus allowing the sudden failure. The variations in the neutral axis are due to the greater deformation in the upper fiber of Beam No. 66 causing the lowering of its position. The stress in the steel as computed from the resisting moment and deformations in steel agree very closely, showing that there is no slipping of bars.

A single Beam No. 71 was made using 1.66% reinforcement and also 10 1/2-in. stirrups spaced 12 in. apart between load points and supports. This increase in reinforcements, did not increase the strength of the beam and the spacing of the stirrups was too great to prevent failure by the diagonal tension, but did prevent the splitting along the top of the bars to some extent and entirely prevented the shearing, thus giving the advantage of a slow failure of the beam, with a greater strength after maximum. The deformations agree fairly well with Beams No. 63, and 67 and position of neutral axis agrees very well with Beams No. 62, 63 and 67. The diagonal tension cracks

tend to follow the stirrups for a short distance up the beam, which is probably due to the weakening of the section at this point due to the stirrups. The stress in the steel as computed from the resisting moment is 10% less than that figured to give the deformation of the steel, which is probably due to error in the measurement of the deformation.

CONCLUSION: In reviewing the results of the tests of these beams, the author considers that the use of 1 percent of Johnson bars reinforcement with stirrups, say, 6 in. apart, will give the greatest strength for beams of this mixture for the following reasons, (1) That the concrete will stand about 1200 lb. per sq. in. compressive stress and with 1% reinforcement, will give about this stress, (2) That the diagonal tension cracks tend to run up the stirrup and then diagonally, at a greater angle, making it necessary to space the stirrups to entirely eliminate this.

MIXTURE 1-3-5 1/2.

In twin Beams No. 58 and 60, having 2-3/4 in. plain round bars, 1.10 percent reinforcement, the maximum loads agree very well. The deformations agree fairly well, until at maximum load, when in Beam No. 58, the deformations are greater which is probably due to the slipping of reinforcing bars for as may be seen, that the stress in steel of Beam 58, as computed from the resisting moment is 30 percent less than that from deformation and may be due to continuing the load after maximum was reached. This difference in computed stress in the steel of Beam No. 60 is true but to a less extent. Compression appears more quikly after maximum load in Beam 58, which is probably due to less

friction on the bars. The positions of the neutral axis agree very well, showing that the same conditions were true in both beams. The compressive stress in upper fiber was about 80% of ultimate compressive stress of the cubes.

In Beams No. 64 and 65 the effect of mixing the concrete just one-half as much for ordinary beams, was not noticeable on the strength of the beams, showing that they were not mixed poorly enough to materially effect the strength. This shows that small variations in mixing of concrete does not impair its strength, for this percentage of reinforcement. These beams gave practically the same results as Beams No. 58 and 60. The stress in the steel as computed from resisting moment was 25% less than that from deformation, which is probably due to the cracking of the beams by accident, while in Beam No. 64 these stresses were the same. The neutral axis was lower in Beam. No. 65 than in No. 64 probably due to fissures. The accidental breaking of beam did not appear to have affected its strength. In Beam No. 65, diagonal tension appeared shortly after maximum, probably at a poorly mixed portion of the beam.

Beams No. 72 and 73 were poorly mixed with 1 in. of top of 1-3 mortar, 1.10% reinforcements, 2-3/4-in. plain round bars with 10-1/2-in. stirrups placed 12 in. apart. The effect of the poor mixing was not noticeable, showing as above that the mixing was not poor enough to materially impair the strength. The maximum loads and deformations of these beams agree very well with above beams, using the same percent of reinforcement. The stress in the steel, as computed from the resisting moments

are about 20 to 25 percent less than from deformations, showing that there must have been a slipping of the bars at maximum load. The positions of the neutral axis agree very well with those of above beams. Diagonal tension started shortly after maximum load of 10000 lb. but did not cause failure of beam and were probably due to defective parts in concrete due to uneven mixing. The stirrups were of no benefit as was shown by the beam without them. The ultimate stress of the concrete as obtained from cube tests was not exceeded in the upper fiber of beams.

In Beam No. 68 and 70, 1.66% reinforcements, were increased to 3-3/4-in. plain round bars, with stirrups as in Beams No. 72, and 73. The maximum loads agree very well but Beam No. 68 failed by diagonal tension and No. 70 by compression. The deformation in steel agree very well up to load of 13000 lb. but those of upper fiber of Beam. No. 70 differ considerably, this is due in part, that it failed by compression. The stress in the steel of Beam No. 70 as computed from resisting moment is 20% less than from deformations, which shows that there was a small slipping of thebars at maximum load, while for Beam No. 68 these stresses agree very well. Diagonal tension started similarly at both ends, and increasing the compressive stress in concrete. In Beam No. 68, the diagonal tension, which caused the failure of beam, was due to the too great spacing of stirrup to eliminate this. The position of the neutral axis is higher for beam No. 68 due to No. 70 failing by compression. In Beam No. 68 crushing appeared at north load point due to concentrat-

ing of compression by the opening of diagonal cracks. The stress in the steel, as computed from the resisting moment a and that from deformations agree, showing that there were no slipping of bars in Beam No. 68, but in No. 70 it is 20% less than in the former, showing that a small slipping occurred. The results of these two tests tend to show that this is about the maximum load for this compositions, as they are equally liable to fail by compression or diagonal tension, but the ultimate compressive strength of the cubes was not exceeded, which shows that failure by compression must have occurred at a defective spot.

CONCLUSION: From the results of the tests of 1-3-5 1/2 beams, the greatest strength can be obtained with the use of stirrups and 1.66% reinforcement of plain round bars, but the author considers that a beam with 1.25% reinforcement of Johnson bars, with stirrups spaced, say, 6 in. apart will develop a greater resisting moment for the following reasons, (1) The manner in which the diagonal cracks opened up in beam would demand that the spacing of stirrups should be close in order to eliminate this, (2) The use of the Johnson bar will avoid the slipping of the bars at maximum and allow steel to carry a greater stress, as the concrete is capable of sustaining a greater stress than has occurred in beams of this mixture as shown by tests of cubes. With the degree of poor mixing given to the beams, it was found to do no material harm to the beam with 1.10% reinforcement of plain round bars, but consider that with 4-1/2 in. Johnson bars that the stirrups should

be spaced 6 in. apart as the increased bond of bars will avoid slipping of bars and give it greater strength, thus increasing the liability of diagonal tension. The author considers that the use of the same percent of reinforcement and bars will give a greater strength to beams of 1-3-5 1/2 mixture.

MIXTURE 1-2-4.

In Beams No. 59 and 61, with 2-3/4-in. plain round bars, the maximum loads agreed very well as do the deformations of steel and upper fiber. The stress in the steel as computed from the resisting moment and deformations agree very closely and show that the elastic limit has not been exceeded and there is no slipping of the bars. The position of the neutral axis is very nearly the same for both beams from load of 7000-lb. The deformations seemed to be erratic at first for loads in Beam No. 61, probably due to eccentric loading. The compressive stress developed in beams is about 60% of ultimate compressive strength of cubes.

A single Beam No. 69 contained 3-3/4-in. plain round bars and 10-1/2-in. stirrups, increased the maximum load 33 1/3 percent, there were no signs of slipping or failure of bond. The stresses in the steel as computed from the resisting moment and deformations showed that the stress in the steel had not exceeded the leastic limit. The load dropped slowly after maximum, showing that the friction of the bars in concrete is nearly enough to hold beam at maximum load. The neutral axis rises rapidly after maximum showing failure by tension.

CONCLUSION: From these tests of 1-2-4 concrete, it is clearly shown, that it can carry a greater load with a greater amount of steel and the author considers that the strength could be increased by the use of 1.5% of Johnson bar reinforcement and with stirrups placed say 6 in. apart for the following reasons: (1) The increasing the bond and amount of stress the steel can carry will increase the diagonal tension cracks that appeared in Beam No. 69 and at this inclination would require spacing of 6 in. to eliminate. (2) The increase of steel will throw a greater stress into the concrete, which it could carry, as was shown in Beam No. 69, which compressive stress of upper fiber amounted to 60 percent of the ultimate stress of the cubes.

SUMMARY.

In the above test, it is seen that the strength of the beam varies as some function of the mixture of concrete, being stronger for the richer concrete. In using mixture of 1-5-10 concrete as basis, the strength of beam is increased as follows: for 1.10 percent reinforcement of plain roundbars, 1-3-5 1/2, increase of 25 percent, 1-2-4, increase of 50 percent; for 1.66 percent reinforcement of plain round bars, with 10-1/2-in. stirrups, for 1-3-5 1/2 increase of 75 percent; 1-2-4, increase 100 percent. With the higher percents of steel, the bond is more important, and is necessary to use bars giving greatest bond in order to stress the steel to its elastic limit. In the above tests the elastic limit of the bars determined from tests of steel, was in no case exceeded as computed from

the resisting moment. With very lean mixtures, using 1.10 percent reinforcement and richer mixtures using 1.66 percent reinforcement it is necessary to use stirrups, spaced say 6 in., apart to eliminate failure by diagonal tension. Therefore it is necessary to eliminate the failure of bond of reinforcement and diagonal tension, to give the maximum load for the percent of reinforcement used.

In the above beams with the same percent of reinforcement, the deflections vary with the mixtures, being smaller for the richer concrete. The variation of deflection of beams at load of 8000 lbs. and with deflection of 1-2-4 beams as basis is as follows: for 1.1 percent reinforcement, 26 percent increase, for 1-3-5 1/2 and 40 percent increase for 1-5-10; with 1.66 percent reinforcement, with stirrups 33 percent decrease in 1-2-4, 10 percent decrease in 1-3-5 1/2 and about 25 percent increase in 1-5-10. This shows that the stiffer beams are obtained with use of richer mixtures and higher percent of reinforcement.

## DESCRIPTION OF TABLE 7.

In the following table the position of the neutral axis and some of the stresses in the beams at maximum load are shown. In the first column is given the numbers of the beams as used throughout this thesis. The second column gives the maximum applied load in pounds. In some cases extensometer readings could not be taken at maximum load due to the sudden failure of the beam so the values given in the third column was used, being the load considered in computing the stresses. The fourth column gives the ratio of the depth of the neutral axis to depth of the steel, which was taken from diagram explained in the discussion. The "Moment arm" was computed from Formula $d(1 - 4/11\ K)$, which was derived by Prof. Talbot from tests of plain concrete in compression. The symbols of which are, d = effective depth of beam, or depth of the center of reinforcing bars, = 10 in., K is the position of the neutral axis as used in fourth column. This gives the distance between centroid of compressive forces and center of steel. In the two columns headed the "Stress in Steel" are given, the stresses as found from the unit-deformation of steel times the coefficient of elasticity of the steel (E = 28000000) and stress due to resisting moment which was computed by dividing the maximum bending moment developed in the beam by the moment arm as found in the fifth column. The weight of the beam or apparatus was not considered in computing these stresses, as the zero deformations were taken with the loads. Under "Stress in Concrete", is given

the unit compressive stress in the upper fiber as computed from formula $\frac{2pf}{k}$, symbols of which are, p = percent of reinforcement, f = unit fiber stress in the steel at load considered, and k as computed in fourth column. Area of reinforcing bars are given in next column. The following column gives the unit horizontal shear, computed from formula $\frac{V}{bd'}$, v = vertical shear or one-half of the applied load considered, d' = moment arm of fifth column. Unit bond stress was computed from formula $\frac{v}{nod'}$, n = number of rods, o = periphery of bars, and d' = moment arm. In the last column is given the manner of failure of beam, as determined from observations of tests, the deformation in the steel and concrete and position of neutral axis at maxinum load.

Table No. 7.

DATA AND CALCULATED RESULTS FOR

REINFORCED CONCRETE BEAMS.

| No of Beam | Max. Load lb | Load Considered. lb | Neutral Axis k | Mom. Arm in | Stress in Def's. lb/sq. in. | Steel Resist. M | Stress in Concr'e. | Area of Bars Sq. in. | Hor. Unit V. lb/sq. in. | Unit Bond | Manner of Failure. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 58 | 9860 | 9860 | .52 | 8.11 | 45100 | 32800 | 1300 | 0.883 | 76 | 257 | Tension. |
| 60 | 10360 | 10360 | .54 | 8.04 | 39500 | 35100 | 1430 | 0.883 | 81 | 274 | " |
| 59 | 12000 | 12000 | .49 | 8.22 | 40300 | 39700 | 1780 | 0.883 | 91 | 210 | " |
| 61 | 10960 | 10960 | .46 | 8.33 | 34400 | 35600 | 1700 | 0.883 | 82 | 280 | " |
| 62 | 8850 | 8850 | .60 | 7.81 | 30600 | 30600 | 1120 | 0.883 | 71 | 240 | Diag.Ten. |
| 63 | 7360 | 7000 | .48 | 8.26 | 25850 | 23200 | 1070 | 0.883 | 47 | 181 | " |
| 64 | 9850 | 9850 | .55 | 8.00 | 33800 | 33500 | 1340 | 0.883 | 77 | 262 | Tension. |
| 65 | 10000 | 10000 | .53 | 8.08 | 45900 | 33700 | 1400 | 0.883 | 78 | 263 | " |
| 66 | 8000 | 8000 | .70 | 7.46 | 25800 | 25800 | 921 | 1.000 | 67 | 269 | Diag. Ten. |
| 67 | 7850 | 7000 | .55 | 8.00 | 20850 | 21000 | 960 | 1.000 | 55 | 219 | " |
| 68 | 14220 | 14220 | .59 | 7.85 | 35000 | 32900 | 1860 | 1.325 | 114 | 256 | " |
| 70 | 13710 | 13710 | .6~~6~~5 | 7.60 | 41000 | 32700 | 1650 | 1.325 | 113 | 255 | Compression |
| 69 | 16000 | 16000 | .5~~9~~6 | 7.85 | 33500 | 36900 | 2080 | 1.325 | 128 | 288 | Tension. |
| 71 | 7600 | 7600 | .55 | 8.00 | 23600 | 17100 | 1040 | 1.325 | 59 | 134 | Diag.Ten. |
| 72 | 10270 | 10270 | .46 | 8.33 | 44300 | 33600 | 1610 | 0.883 | 77 | 263 | Tension. |
| 73 | 9900 | 9900 | .49 | 8.22 | 39250 | 33000 | 1480 | 0.883 | 75 | 256 | " |

## DESCRIPTION OF CURVES.

On plates 1 to 16 will be found a graphical representation of results obtained from tests of the beams. These diagrams contain four curves showing, first, the contractions of the upper fiber, second, the elongation of the steel, third the actual deflections at the center and fourth, the position of the neutral axis. The values plotted of the unit deformations of the upper fiber and steel are deduced graphically from the extensometer readings.

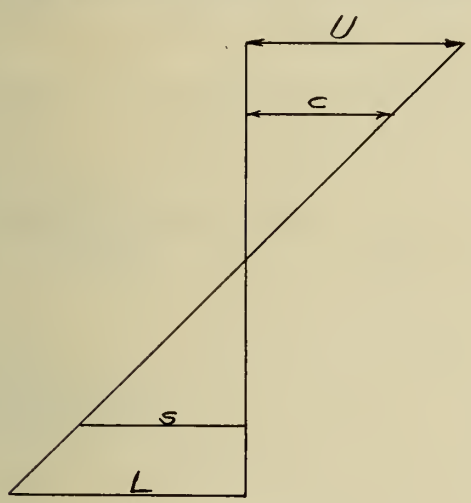



Fig. 3.

A diagram drawn to a large scale on coordinate paper, the principle of which is shown by sketch, was used in the deductions. U is the average total deformation in line of upper extensometer and L is the average total deformation in line of the lower extensometers, and c is therefore the total contraction of the upper fiber of the concrete and s is the true total elongation of steel. Vertical line represents a plane section of beam before bending and the inclined line the plane section after bending, the intersection of which gives the location of the neutral axis K, which is expressed as a ratio of the depth of the neutral axis, to the depth of the beam to the level of the steel.

## DESCRIPTION OF TABLES.

On the following pages are given the original readings and a part of the derived value for the beams. The first columns give the applied load in pounds and does not include weight of beam or apparatus. Under the heading of "Original Readings", columns numbered 1,3,2 and 4 are headed, "Extensometer", are the original readings for the four extensometers and are taken directly in decimals of an inch. The sub-headings 1, 3, 2 and 4 indicate the four extensometers, 1 and 3 are always the upper extensometers and 2 and 4 the lower, 1 and 4 being on one side and 3 and 2 on the other. In column headed "Deflections" are given the deflection from the position of zero load. In the two columns headed "Unit Deformations" are given the deformations per unit of length for the fiber indicated in the sub-heading, computed with reference to zero deformation at first zero of applied load. In the remaining columns is given the position of the neutral axis as taken from the diagram explained in the discussion. The values for the unit deformations and neutral axis were used in making the curves for plates 7 to 16.

Beam No. 58.

2-3/4in Plain round bars.

1-3-5 1/2.

Size of Beam. 8 in. x 11 in. x 13 ft. Span. 12 ft.

| Appl'd Load. lbs. | Original Readings. Extensometer Inches. 1 | 3 | 2 | 4 | Def's Inches. | Unit Defor'ns. Upper Fiber. .001-in. | Steel. | Neutral Axis. |
|---|---|---|---|---|---|---|---|---|
| 1000 | .0058 | .0059 | .0043 | .0048 | .025 | .059 | .040 | 64 |
| 2000 | .0143 | .0149 | .0127 | .0131 | .075 | .139 | .104 | 57 |
| 3000 | .0276 | .0291 | .0223 | .0278 | .125 | .270 | .204 | 57 |
| 4000 | .0426 | .0458 | .0433 | .0449 | .181 | .404 | .381 | 52 |
| 5000 | .0601 | .0645 | .0622 | .0632 | .244 | .561 | .545 | 51 |
| 6000 | .0775 | .0834 | .0800 | .0803 | .300 | .735 | .689 | 51 |
| 7000 | .0989 | .1074 | .1019 | .1005 | .356 | .944 | .862 | 52 |
| 8000 | .1228 | .1347 | .1238 | .1213 | .413 | 1.194 | 1.032 | 54 |
| 9000 | .1482 | .1687 | .1494 | .1471 | .556 | 1.480 | 1.232 | 55 |
| 9860 | .1585 | .2215 | .1897 | .1867 | .694 | 1.720 | 1.610 | 52 |
| 9000 | .1607 | .3747 | .2894 | .3080 | .994 | 2.312 | 2.740 | 46 |
| 7350 | | | | | 1.250 | | | |

Beam No. 59.

2-3/4 in Plain round bars.

1-2-4.

Size of Beam. 8 in. x 11 in. x 13 ft. Span 12 ft.

| Appl'd Load. lbs. | Original Readings. Extensometer Inches. 1 | 3 | 2 | 4 | Def's Inches. | Unit Defor'ns Upper Fiber. .001-in. | Steel. | Neutral Axis. |
|---|---|---|---|---|---|---|---|---|
| 1000 | .0059 | .0070 | .0055 | .0073 | .006 | .061 | .055 | 52 |
| 2000 | .0116 | .0140 | .0125 | .0141 | .031 | .114 | .120 | 49 |
| 3000 | .0185 | .0215 | .0190 | .0218 | .081 | .182 | .173 | 51 |
| 4000 | .0278 | .0310 | .0290 | .0314 | .106 | .257 | .286 | 50 |
| 5000 | .0385 | .0412 | .0409 | .0424 | .139 | .358 | .368 | 49 |
| 6000 | .0505 | .0530 | .0545 | .0546 | .193 | .457 | .489 | 49 ~~48~~ |
| 7000 | .0640 | .0655 | .0685 | .0679 | .250 | .582 | .598 | 49 ~~50~~ |
| 8000 | .0779 | .0790 | .0830 | .0819 | .313 | .702 | .725 | 49 |
| 9000 | .0922 | .0932 | .0968 | .0961 | .375 | .829 | .848 | 49 ~~50~~ |
| 10000 | .1074 | .1080 | .1120 | .1109 | .431 | .957 | .967 | 49 |
| 11000 | .1248 | .1250 | .1300 | .1262 | .494 | 1.128 | 1.119 | 50 |
| 12000 | .1578 | .1522 | .1690 | .1561 | .606 | 1.381 | 1.435 | 49 |
| 11850 | | | | | 1.194 | | | |
| 10000 | | | | | 1.819 | | | |

Beam No. 60.

2-3/4 in Plain round bars.

1-3-5 1/2.

Size of Beam. 8 in. x 11 in. x 13 ft. Span. 12 ft.

| Appl'd Load. lbs. | Original Readings. Extensometer Inches. 1 | 3 | 2 | 4 | Def's Inches. | Unit Defor'ns. Upper Fiber. .001-in. | Steel. | Neutral Axis. |
|---|---|---|---|---|---|---|---|---|
| 1000 | .0055 | .0045 | .0050 | .0041 | .019 | .048 | .038 | 57 |
| 2000 | .0121 | .0110 | .0115 | .0100 | .038 | .102 | .093 | 54 ~~52~~ |
| 3000 | .0238 | .0223 | .0236 | .0217 | .088 | .209 | .195 | 51 |
| 4000 | .0395 | .0362 | .0400 | .0366 | .125 | .345 | .330 | 51 |
| 5000 | .0552 | .0516 | .0568 | .0525 | .200 | .486 | .475 | 50 ~~51~~ |
| 6000 | .0709 | .0680 | .0725 | .0675 | .263 | .632 | .609 | 51 |
| 7000 | .0886 | .0860 | .0900 | .0830 | .325 | .800 | .740 | 52 |
| 8000 | .1085 | .1060 | .1078 | .1001 | .400 | .990 | .877 | 53 |
| 9000 | .1309 | .1290 | .1270 | .1185 | .469 | 1.220 | 1.021 | 54 |
| 10000 | .1569 | .1568 | .1493 | .1399 | .563 | 1.478 | 1.190 | 55 ~~54~~ |
| 10360 | .1803 | .1805 | .1750 | .1637 | .644 | 1.690 | 1.409 | 54 |
| 10000 | .3705 | .3700 | .4510 | .3818 | 1.250 | 3.180 | 3.785 | 46 |
| 9000 | | | | | 2.038 | | | |

Beam No. 61.

2-3/4 in Plain Round Bars.

1-2-4.

Size of Beam. 8 in. x 11 in. x 13 ft. Span.12 ft.

| Appl'd load. lbs. | Original Readings. Extensometer Inches 1 | 3 | 2 | 4 | Def's Inches. | Unit Defor'ns Upper Fiber. | Steel. .001-in. | Neutral Axis. |
|---|---|---|---|---|---|---|---|---|
| 1000 | .0039 | .0040 | .0038 | .0034 | .019 | .038 | .029 | 57 |
| 2000 | .0081 | .0076 | .0030 | .0074 | .044 | .084 | .032 | 72 |
| 3000 | .0149 | .0155 | .0080 | .0139 | .063 | .157 | .075 | 67 |
| 4000 | .0250 | .0255 | .0186 | .0246 | .094 | .244 | .166 | 60 |
| 5000 | .0400 | .0395 | .0357 | .0414 | .156 | .368 | .325 | 54 |
| 6000 | .0552 | .0550 | .0545 | .0597 | .219 | .495 | .500 | 50 |
| 7000 | .0660 | .0620 | .0667 | .0719 | .281 | .563 | .618 | 48 |
| 8000 | .0793 | .0785 | .0818 | .0852 | .319 | .684 | .785 | 47 |
| 9000 | .0924 | .0915 | .0955 | .1006 | .375 | .811 | .868 | 48 |
| 10000 | .1053 | .1020 | .1100 | .1151 | .438 | .906 | 1.012 | 47 |
| 10960 | .1222 | .1220 | .1300 | .1411 | .513 | 1.157 | 1.229 | 46 |
| 10400 | .4079 | .5700 | .6200 | .6437 | 1.794 | 3.820 | 6.110 | 48 |
| 10400 | | | | | 2.281 | | | |
| 10400 | | | | | | | | |

Beam No. 62.

2-3/4in Plain Round Bars.

1-5-10.

Size of Beam. 8 in. x 11 in. x 13 ft. Span. 12 ft.

| Appl'd Load. lbs. | Original Readings. Extensometer Inches. 1 | 3 | 2 | 4 | Def's Inches. | Unit Defor'ns Upper Fiber. | Steel. .001-in. | Neutral Axis. |
|---|---|---|---|---|---|---|---|---|
| 1000 | .0090 | .0105 | .0100 | .0125 | .044 | .082 | .135 | 44 |
| 2000 | .0194 | .0204 | .0210 | .0251 | .075 | .168 | .212 | 44 |
| 3000 | .0309 | .0325 | .0330 | .0386 | .125 | .272 | .327 | 45 |
| 4000 | .0449 | .0530 | .0420 | .0537 | .188 | .443 | .415 | 51 |
| 5000 | .0599 | .0700 | .0600 | .0686 | .238 | .579 | .548 | 52 |
| 6000 | .0775 | .0900 | .0862 | .0859 | .325 | .758 | .752 | 50 |
| 7000 | .0983 | .1140 | .0942 | .1060 | .400 | .988 | .847 | 54 |
| 8000 | .1241 | .1420 | .1155 | .1280 | .488 | 1.256 | .997 | 56 |
| 8500 | .1408 | .1620 | .1285 | .1419 | .553 | 1.440 | 1.091 | 57 |
| 8850 | .1600 | .1820 | .1380 | .1470 | .638 | 1.680 | 1.095 | 60 |
| 3000 | | | | | .763 | | | |

Beam No. 63.

2-3/4 in Plain Round Bars.

1-5-10.

Size of Beam. 8 in. x 11 in. x 13 ft. Span. 12 ft.

| Appl'd Load. lbs. | Original Readings. Extensometer Inches. 1 | 3 | 2 | 4 | Def's Inches. | Unit Defor'ns Upper Fiber. .001-in. | Steel. | Neutral Axis. |
|---|---|---|---|---|---|---|---|---|
| 1000 | .0041 | .0080 | .0075 | .0089 | .031 | .046 | .080 | 37 |
| 2000 | .0153 | .0203 | .0200 | .0222 | .081 | .146 | .198 | 43 |
| 3000 | .0242 | .0350 | .0335 | .0369 | .131 | .246 | .329 | 43 |
| 4000 | .0358 | .0500 | .0475 | .0515 | .188 | .363 | .457 | 44 |
| 5000 | .0454 | .0680 | .0640 | .0668 | .256 | .479 | .604 | 44 |
| 6000 | .0568 | .0905 | .0845 | .0837 | .344 | .627 | .772 | 45 |
| 7000 | .0742 | .1175 | .1050 | .1017 | .438 | .839 | .923 | 48 |
| 7360 | | | | | .969 | | | |

Beam No. 64

2-3/4 in Plain Round Bars.

1-3-5 1/2, Poorly Mixed.

Size of Beam. 8 in. x 11 in. x 13 ft. Span. 12 ft.

| Appl'd Load. lbs. | Original Readings. Extensometer Inches. 1 | 3 | 2 | 4 | Def's Inches. | Unit Defor'ns Upper Fiber .001-in. | Steel. | Neutral Axis. |
|---|---|---|---|---|---|---|---|---|
| 1000 | .0050 | .0056 | .0039 | .0049 | .025 | .052 | .034 | 60 |
| 2000 | .0125 | .0142 | .0108 | .0128 | .056 | .129 | .095 | 58 |
| 3000 | .0223 | .0250 | .0208 | .0239 | .100 | .218 | .191 | 53 |
| 4000 | .0342 | .0392 | .0348 | .0380 | .150 | .332 | .314 | 51 |
| 5000 | .0376 | .0540 | .0495 | .0523 | .213 | .464 | .437 | 52 |
| 6000 | .0622 | .0700 | .0650 | .0676 | .275 | .604 | .568 | 52 |
| 7000 | .0782 | .0880 | .0822 | .0839 | .338 | .758 | .715 | 52 |
| 8000 | .0962 | .1080 | .1000 | .1007 | .400 | .936 | .854 | 52 |
| 9000 | .1167 | .1310 | .1200 | .1210 | .488 | 1.139 | 1.020 | 53 |
| 9850 | .1413 | .1590 | .1440 | .1452 | .575 | 1.445 | 1.205 | 55 |
| 9000 | .2050 | .2285 | .2280 | .2330 | .681 | 1.911 | 2.370 | 48 |
| 8900 | | | | | 1.088 | | | |
| 8600 | | | | | 1.838 | | | |

Beam No. 65.

2-3/4in Plain Round Bars.

1-3-5 1/2. Poorly Mixed.

Size of Beam. 8 in. x 11 in. x 13 ft. Span 12 ft.

| Appl'd load. lbs. | Original Readings. Extensometer Inches. 1 | 3 | 2 | 4 | Def's Inches. | Unit Defor'ns Upper Fiber. | Steel. .001-in. | Neutral Axis. |
|---|---|---|---|---|---|---|---|---|
| 1000 | .0086 | .0078 | .0077 | .0073 | .006 | .077 | .061 | 56 |
| 2000 | .0206 | .0200 | .0185 | .0185 | .050 | .195 | .146 | 57 |
| 3000 | .0339 | .0345 | .0300 | .0314 | .088 | .327 | .246 | 57 |
| 4000 | .0486 | .0500 | .0430 | .0465 | .138 | .472 | .364 | 56 |
| 5000 | .0641 | .0680 | .0570 | .0524 | .200 | .630 | .500 | 57 |
| 6000 | .0800 | .0850 | .0727 | .0798 | .263 | .779 | .627 | 55 |
| 7000 | .0964 | .1035 | .0888 | .0967 | .338 | .942 | .763 | 55 |
| 8000 | .1144 | .1240 | .1058 | .1148 | .413 | 1.125 | .908 | 55 |
| 9000 | .1334 | .1455 | .1245 | .1338 | .475 | 1.312 | 1.064 | 55 |
| 10000 | .1729 | .1883 | .1685 | .1777 | .650 | 1.670 | 1.462 | 53 |
| 10000 | .1890 | .2060 | .1920 | .2000 | .694 | 1.840 | 1.642 | 53 |
| 10000 | | | | | 1.000 | | | |
| 9750 | | | | | 1.725 | | | |
| 9000 | .6490 | .6846 | .7249 | .7380 | 2.100 | 2.100 | 6.630 | 46 |

Beam No. 66.

4-1/2in Johnson Bars.

1-5-10.

Size of Beam. 8 in. x 11 in. x 13 ft. Span. 12 ft.

| Appl'd load. lbs. | Original Readings. Extensometer Inches. 1 | 3 | 2 | 4 | Def's Inches. | Unit Defor'ns Upper Fiber .001-in. | Steel. | Neutral Axis. |
|---|---|---|---|---|---|---|---|---|
| 1000 | .0108 | .0120 | .0090 | .0103 | .038 | .111 | .077 | 59 |
| 2000 | .0275 | .0287 | .0218 | .0244 | .089 | .277 | .175 | 61 |
| 3000 | .0454 | .0380 | .0370 | .0406 | .150 | .461 | .282 | 61 |
| 4000 | .0660 | .0690 | .0530 | .0570 | .238 | .671 | .414 | 62 |
| 5000 | .0877 | .0927 | .0705 | .0750 | .300 | .899 | .543 | 62 |
| 6000 | .1150 | .1126 | .0909 | .1050 | .394 | 1.108 | .768 | 59 |
| 7000 | .1525 | .1583 | .1155 | .1202 | .519 | 1.573 | .841 | 65 |
| 8000 | .2370 | .2277 | .1585 | .1569 | .706 | 2.447 | 1.019 | 70 |

Beam No. 67.

4-1/2in Johnson Bars.

1-5-10.

Size of Beam. 8 in. x 11 in. x 13 ft. Span. 12 ft.

| Appl'd load. lbs. | Original Readings. Extensometer Inches. 1 | 3 | 2 | 4 | Def's Inches. | Unit Defor'ns Upper Fiber. .001-in. | Steel. | Neutral Axis. |
|---|---|---|---|---|---|---|---|---|
| 1000 | .0064 | .0059 | .0070 | .0065 | .031 | .054 | .061 | 46 |
| 2000 | .0165 | .0160 | .0185 | .0177 | .063 | .139 | .164 | 46 |
| 3000 | .0287 | .0280 | .0310 | .0306 | .113 | .246 | .277 | 47 |
| 4000 | .0419 | .0418 | .0442 | .0440 | .175 | .366 | .396 | 48 |
| 5000 | .0572 | .0580 | .0585 | .0585 | .225 | .521 | .509 | 51 |
| 6000 | .0742 | .0755 | .0732 | .0732 | .300 | .684 | .629 | 52 |
| 7000 | .0954 | .0970 | .0900 | .0900 | .375 | .901 | .745 | 55 |
| 7850 | | | | | | | | |

Beam No. 68.

3-3/4in Plain Round Bars.

1-3-5 1/2, 10-1/2in Stirrups 12in apart.

Size of Beam. 8 in. x 11 in. x 13 ft. Span. 12 ft.

| Appl'd load. lbs. | Original Readings. Extensometer Inches. 1 | 3 | 2 | 4 | Def's Inches. | Unit Defor'ns Upper Fiber. .001-in. | Steel. | Neutral Axis. |
|---|---|---|---|---|---|---|---|---|
| 1000 | .0050 | .0055 | .0050 | .0043 | .025 | .052 | .0375 | 58 |
| 2000 | .0103 | .0110 | .0108 | .0092 | .038 | .100 | .079 | 55 ~~54~~ |
| 3000 | .0185 | .0185 | .0190 | .0170 | .075 | .170 | .154 | 53 |
| 4000 | .0265 | .0265 | .0280 | .0260 | .106 | .239 | .234 | 51 |
| 5000 | .0362 | .0360 | .0375 | .0356 | .156 | .327 | .318 | 51 |
| 6000 | .0460 | .0460 | .0473 | .0456 | .181 | .418 | .402 | 51 |
| 7000 | .0565 | .0568 | .0575 | .0559 | .225 | .519 | .486 | 51 ~~52~~ |
| 8000 | .0679 | .0685 | .0683 | .0660 | .275 | .626 | .575 | 52 |
| 9000 | .0804 | .0815 | .0800 | .0772 | .313 | .746 | .665 | 53 |
| 10000 | .0947 | .0965 | .0925 | .0890 | .363 | .886 | .761 | 54 |
| 11000 | .1095 | .1120 | .1062 | .1015 | .425 | 1.031 | .865 | 54 |
| 12000 | .1274 | .1300 | .1210 | .1145 | .488 | 1.225 | .962 | 56 |
| 13000 | .1480 | .1508 | .1380 | .1302 | .563 | 1.421 | 1.087 | 57 |
| 14000 | .1770 | .1780 | .1580 | .1710 | .663 | 1.705 ~~1.670~~ | 1.225 ~~1.375~~ | 58 ~~55~~ |
| 14220 | .1880 | .1875 | .1650 | .1550 | .719 | 1.830 | 1.250 | 59 |
| 13000 | .2000 | .1920 | .1655 | .1560 | .825 | 1.948 | 1.215 | 61 |
| 10000 | .1800 | .1950 | .1540 | .1350 | 1.119 | 1.859 | 1.090 | 65 |
| 8000 | | | | | 1.469 | | | |

Beam No. 69.

3-3/4 in Plain Round Bars.

1-2-4, 10-1/2 in stirrups 12 in apart.

Size of Beam 8 in. x 11 in. x 13 ft. Span. 12 ft.

| Appl'd load. lbs. | Original Readings. Extensometer Inches. 1 | 3 | 2 | 4 | Def's Inches. | Unit Defor'ns Upper Fiber. .001-in. | Steel. | Neutral Axis. |
|---|---|---|---|---|---|---|---|---|
| 1000 | .0055 | .0060 | .0058 | .0049 | .013 | .0536 | .046 | 54 |
| 2000 | .0114 | .0125 | .0120 | .0053 | .044 | .1232 | .059 | 67 |
| 3000 | .0178 | .0197 | .0187 | .0057 | .069 | .2001 | .075 | 73 |
| 4000 | .0239 | .0265 | .0252 | .0097 | .088 | .263 | .116 | 70 |
| 5000 | .0306 | .0349 | .0322 | .0161 | .113 | .334 | .159 | 66 |
| 6000 | .0374 | .0410 | .0390 | .0238 | .144 | .389 | .236 | 62 |
| 7000 | .0453 | .0492 | .0466 | .0325 | .175 | .465 | .306 | 60 |
| 8000 | .0533 | .0575 | .0543 | .0413 | .200 | .536 | .378 | 59 |
| 9000 | .0620 | .0665 | .0627 | .0508 | .238 | .613 | .457 | 58 |
| 10000 | .0718 | .0766 | .0728 | .0615 | .275 | .704 | .547 | 56 |
| 11000 | .0824 | .0879 | .0813 | .0727 | .338 | .807 | .628 | 56 |
| 12000 | .0937 | .0998 | .0915 | .0848 | .363 | .918 | .719 | 56 |
| 13000 | .1065 | .1130 | .1018 | .0982 | .431 | 1.051 | .819 | 56 |
| 14000 | .1199 | .1293 | .1141 | .1122 | .481 | 1.180 | .925 | 56 |
| 15000 | .1329 | .1449 | .1259 | .1367 | .525 | 1.324 | 1.027 | 56 |
| 16000 | .1504 | .1660 | .1421 | .1488 | .588 | 1.493 | 1.192 | 59 |
| 15700 | .1670 | .1848 | .1650 | .1631 | .625 | 1.622 | 1.428 | 53 |
| 15300 | .3681 | .3865 | .4312 | .4398 | 1.306 | 3.181 | 4.040 | 44 |
| 14000 | .4420 | .4810 | .4795 | .5170 | 1.525 | 4.060 | 4.560 | 48 |
| 12000 | .6180 | .6665 | .6043 | .6490 | 1.994 | 5.890 | 5.330 | 52 |
| 11000 | .7870 | .8500 | .6910 | .7290 | 2.300 | 7.900 | 5.630 | 58 |

Beam NO.70.

3-3/4 in Plain Round Bars.

1-3-5 1/2, 10 1/2 in stirrups, 12 in apart.

Size of Beam. 8 in. x 11 in. x 13 ft. Span. 12 ft.

| Appl'd Load. lbs. | Original Readings. Extensometer Inches. 1 | 3 | 2 | 4 | Def's Inches. | Unit Defor'ns. Upper Fiber. .001-in. | Steel. | Neutral Axis. |
|---|---|---|---|---|---|---|---|---|
| 1000 | .0051 | .0055 | .0050 | .0053 | .031 | .048 | .045 | 52 |
| 2000 | .0131 | .0140 | .0125 | .0135 | .063 | .127 | .109 | 54 |
| 3000 | .0223 | .0235 | .0210 | .0225 | .094 | .2140 | .181 | 54 |
| 4000 | .0335 | .0350 | .0310 | .0334 | .125 | .3230 | .270 | 54 |
| 5000 | .0448 | .0465 | .0415 | .0440 | .188 | .430 | .356 | 55 |
| 6000 | .0573 | .0595 | .0525 | .0548 | .219 | .553 | .442 | 55 |
| 7000 | .0718 | .0740 | .0645 | .0666 | .281 | .694 | .531 | 56 |
| 8000 | .0848 | .0895 | .0715 | .0787 | .338 | .845 | .589 | 59 |
| 9000 | .1015 | .1082 | .0900 | .0919 | .388 | 1.013 | .724 | 59 |
| 10000 | .1211 | .1275 | .1093 | .1062 | .469 | 1.206 | .850 | 58 ~~59~~ |
| 11000 | .1469 | .1523 | .1270 | .1224 | .531 | 1.469 | .961 | 60 |
| 12000 | .1731 | .1805 | .1457 | .1400 | .625 | 1.756 | 1.071 | 62 |
| 13000 | .2166 | .2210 | .1730 | .1642 | .750 | 2.235 | 1.197 | 64 ~~65~~ |
| 13710 | .2825 | .2825 | .2240 | .2019 | .925 | 2.915 | 1.464 | 66 |
| 13000 | .3840 | .3790 | .3375 | .2730 | 1.188 | 3.590 | 2.270 | 63 |
| 12000 | .4880 | .4750 | .3720 | .3380 | 1.438 | 4.950 | 2.483 | 66 |
| 11000 | .6190 | .6000 | .4500 | .4130 | 1.781 | 6.330 | 2.930 | 68 |
| 10000 | .7450 | .7200 | .5010 | .4910 | 2.063 | 7.700 | 3.210 | 71 |

Beam No. 71.

3-3/4 in. Plain Round Bars.

1-5-10, 10 1/2 in. Stirrups 12-in apart.

Size of Beam. 8 in. x 11 in. x 13 ft. Span. 12 ft.

| Appl'd Load. lbs. | Original Readings. Extensometer Inches. 1 | 3 | 2 | 4 | Def's Inches. | Unit Defor'ns Upper Fiber. .001-in. | Steel. | Neutral Axis. |
|---|---|---|---|---|---|---|---|---|
| 1000 | .0068 | .0067 | .0072 | .0073 | .013 | .059 | .066 | 48 |
| 2000 | .0163 | .0162 | .0165 | .0161 | .063 | .148 | .141 | 51 |
| 3000 | .0271 | .0270 | .0265 | .0276 | .094 | .246 | .236 | 51 |
| 4000 | .0394 | .0400 | .0377 | .0388 | .131 | .368 | .324 | 53 |
| 5000 | .0532 | .0540 | .0495 | .0505 | .188 | .506 | .414 | 55 |
| 6000 | .0689 | .0700 | .0620 | .0630 | .244 | .663 | .507 | 57 |
| 7000 | .0879 | .0890 | .0770 | .0772 | .313 | .851 | .620 | 58 |
| 7600 | .1099 | .1105 | .0962 | .1081 | .406 | 1.039 | .843 | 55 |
| 6000 | .1066 | .1057 | .0925 | .0849 | .469 | 1.040 | .688 | 60 |
| 5000 | .1022 | .1025 | .0900 | .0790 | .541 | 1.005 | .645 | 61 |
| 4000 | .0868 | .1125 | .1052 | .0734 | .869 | .950 | .724 | 57 |
| 3550 | | | | | 1.656 | | | |

Beam No. 72.

2-3/4in Plain Round Bars.

1-3-5 1/2, Poorly mixed, 10 1/2in stirrups 12in apart with 1in of top.

Size of Beam. 8 in. x 11 in. x 13 ft. Span. 12 ft.

| Appl'd Load. lbs. | Original Readings. Extensometer Inches. 1 | 3 | 2 | 4 | Def's Inches. | Unit Defor'ns Upper Fiber. .001-in. | Steel. | Neutral Axis. |
|---|---|---|---|---|---|---|---|---|
| 1000 | .0057 | .0060 | .0050 | .0057 | .019 | .055 | .045 | 56 |
| 2000 | .0129 | .0155 | .0145 | .0161 | .050 | .125 | .138 | 48 |
| 3000 | .0228 | .0269 | .0262 | .0295 | .081 | .213 | .239 | 45 |
| 4000 | .0353 | .0395 | .0400 | .0447 | .144 | .318 | .388 | 45 |
| 5000 | .0496 | .0538 | .0555 | .0613 | .231 | .445 | .533 | 45 |
| 6000 | .0633 | .0682 | .0710 | .0784 | .300 | .559 | .685 | 45 |
| 7000 | .0785 | .0840 | .0868 | .0960 | .394 | .699 | .834 | 45 |
| 8000 | .0956 | .1015 | .1042 | .1154 | .425 | .847 | 1.000 | 46 |
| 9000 | .1148 | .1217 | .1240 | .1361 | .494 | .994 | 1.185 | 46 |
| 10000 | .1360 | .1438 | .1454 | .1592 | .581 | 1.217 | 1.370 | 47 |
| 10270 | .1519 | .1635 | .1662 | .1824 | .644 | 1.361 | 1.581 | 46 |
| 9530 | .1927 | .2080 | .2220 | .2396 | .769 | 1.715 | 2.126 | 45 |
| 9200 | .4520 | .4655 | .5285 | .5560 | 1.519 | 3.823 | 5.060 | 43 |

Beam No. 73.

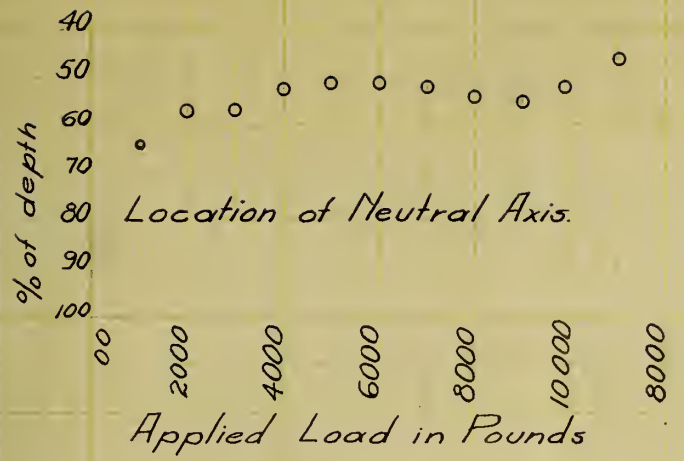
2-3/4 in. Plain Round Bars.

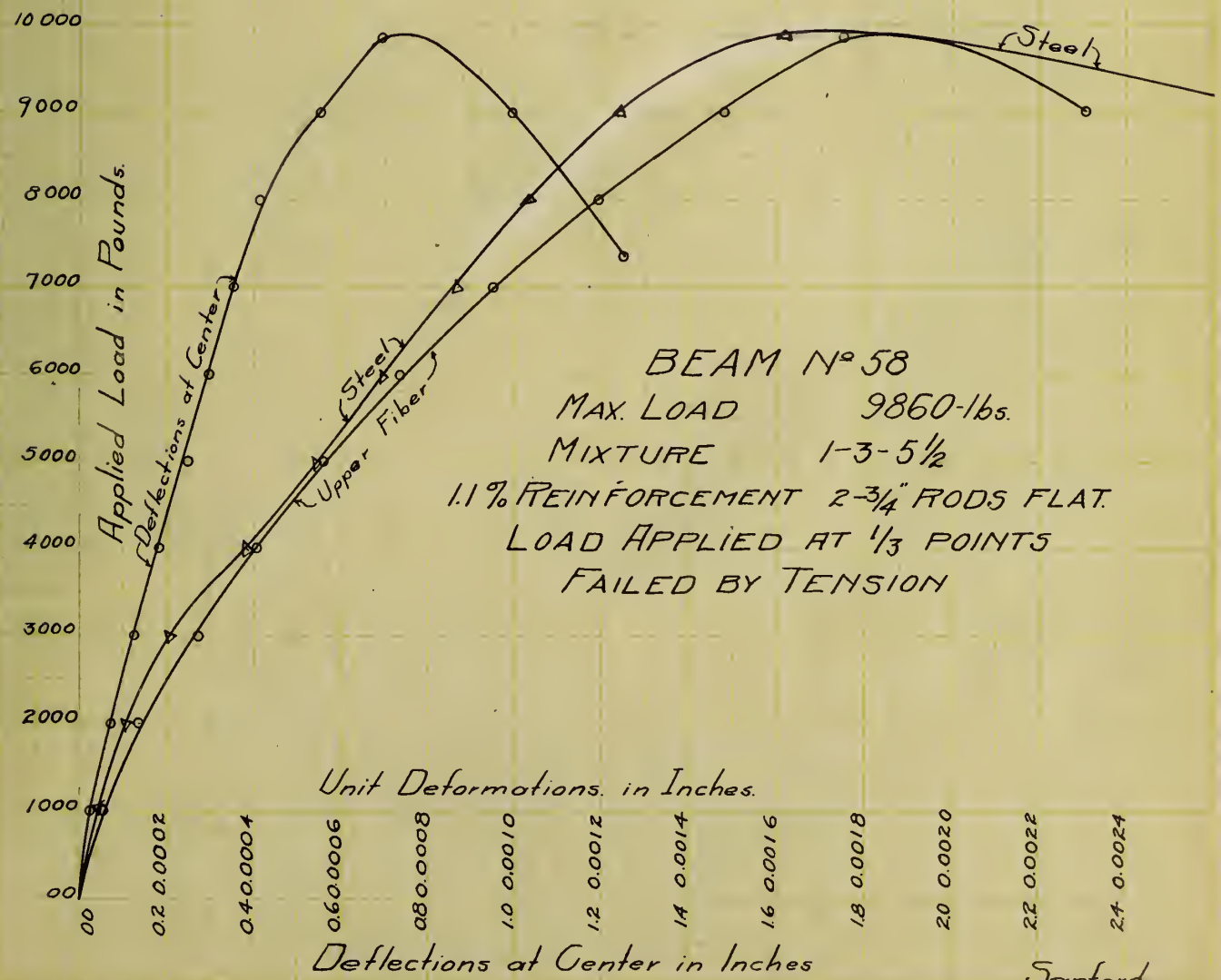
1-3-5 1/2, Poorly mixed, 10 1/2 in. stirrups 12" apart with 1 in. of top.

Size of Beam. 8 in. x 11 in. x 13 ft. Span. 12 ft.

| Appl'd Load. lbs. | Original Readings. Extensometer Inches. 1 | 3 | 2 | 4 | Def's Inches. | Unit Defor'ns Upper Fiber ..001-in. | Steel. | Neutral Axis. |
|---|---|---|---|---|---|---|---|---|
| 1000 | .0053 | .0050 | .0045 | .0046 | .025 | .050 | .038 | 58 |
| 2000 | .0134 | .0130 | .0132 | .0130 | .056 | .119 | .113 | 52 |
| 3000 | .0253 | .0250 | .0275 | .0268 | .106 | .222 | .243 | 48 |
| 4000 | .0380 | .0375 | .0425 | .0410 | .163 | .326 | .381 | 46 |
| 5000 | .0512 | .0510 | .0570 | .0556 | .213 | .443 | .511 | 46 |
| 6000 | .0658 | .0655 | .0725 | .0703 | .275 | .570 | .645 | 47 |
| 7000 | .0808 | .0800 | .0875 | .0850 | .338 | .704 | .772 | 48 |
| 8000 | .0978 | .0975 | .1040 | .1008 | .400 | .865 | .905 | 49 |
| 9000 | .1164 | .1170 | .1210 | .1173 | .463 | 1.047 | 1.041 | 50 |
| 9900 | .1493 | .1545 | .1585 | .1588 | .588 | 1.347 | 1.398 | 49 |
| 9350 | .2109 | | | .2416 | .813 | 1.787 | 2.235 | 44 |
| 9000 | .4320 | .4440 | .5000 | .5010 | 1.494 | 3.720 | 4.610 | 44 |
| 8000 | .5510 | .5600 | .5900 | .6030 | 1.869 | 4.900 | 5.330 | 48 |
| 7000 | | | | | 1.963 | | | |

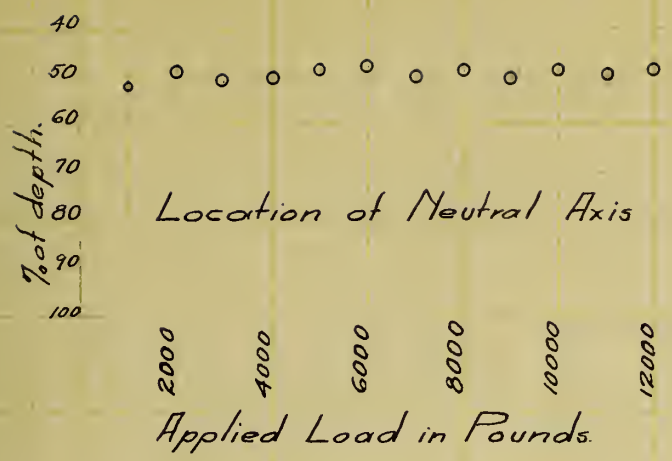
PLATE 1




Sanford

PLATE. 2.



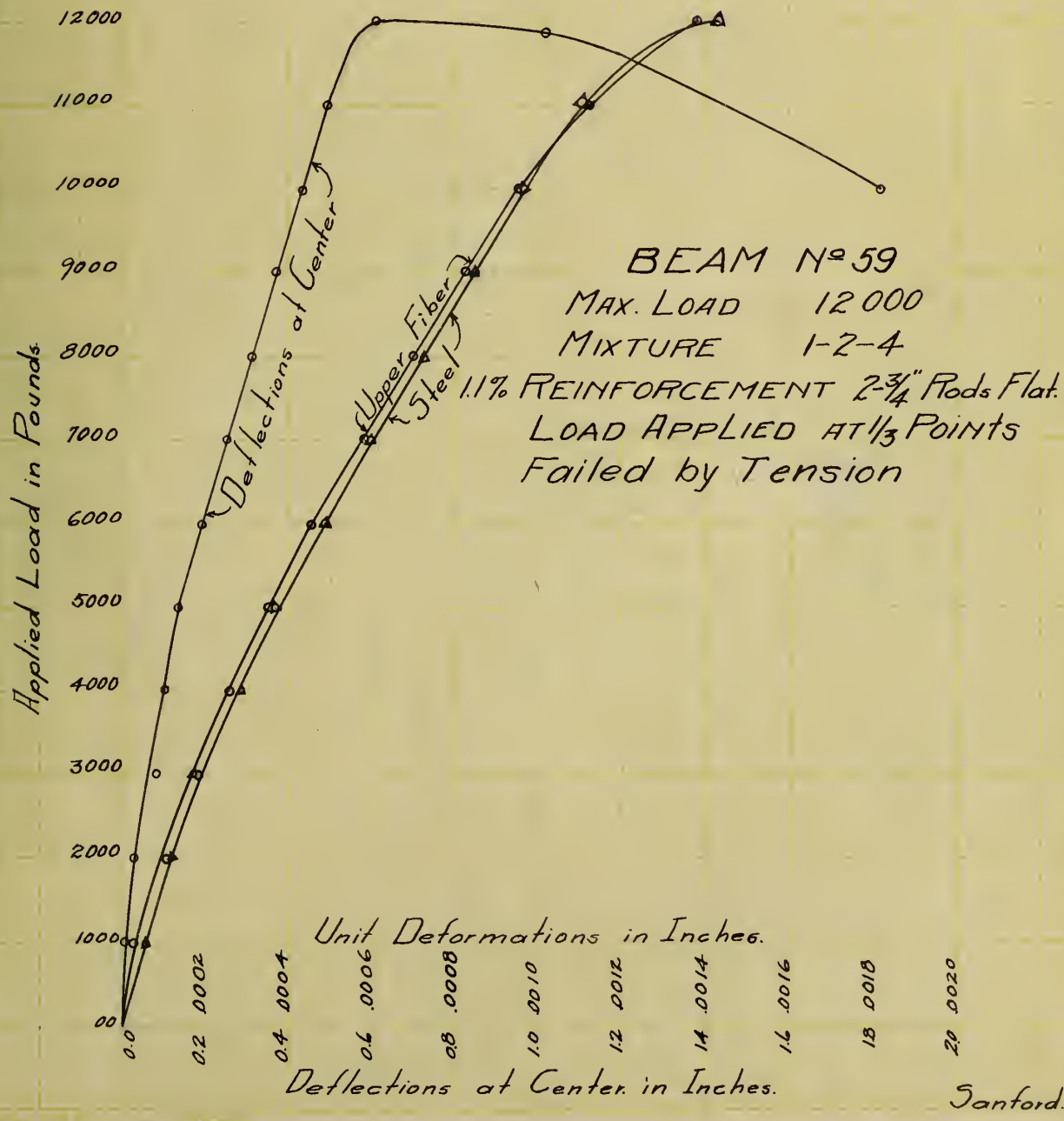




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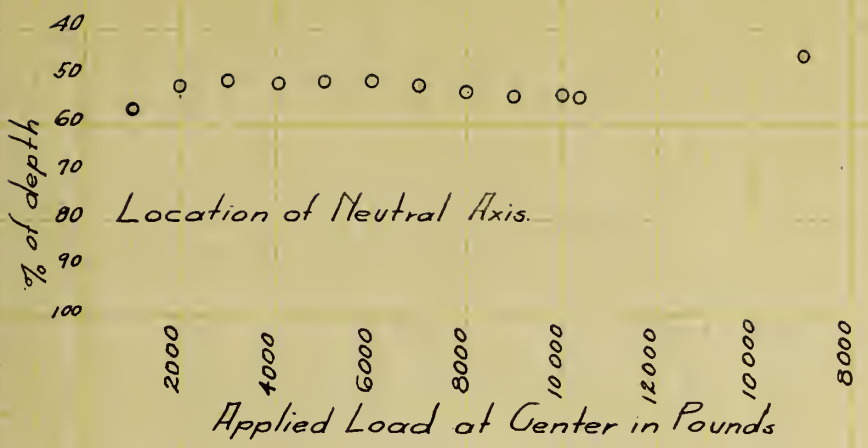
PLATE 3



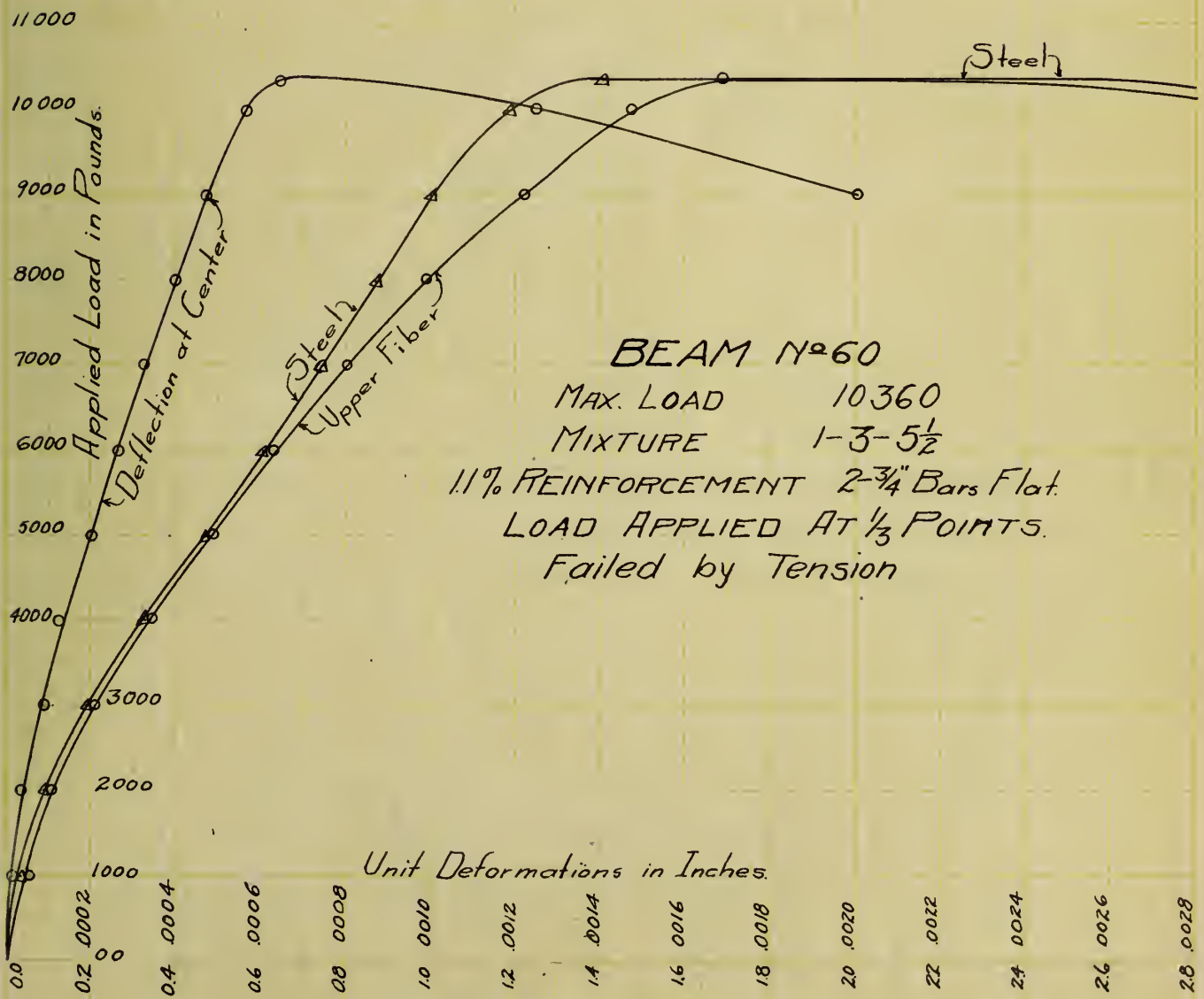




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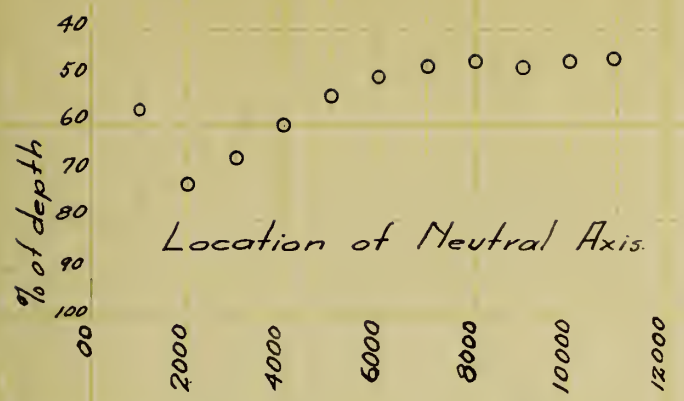
PLATE 4.



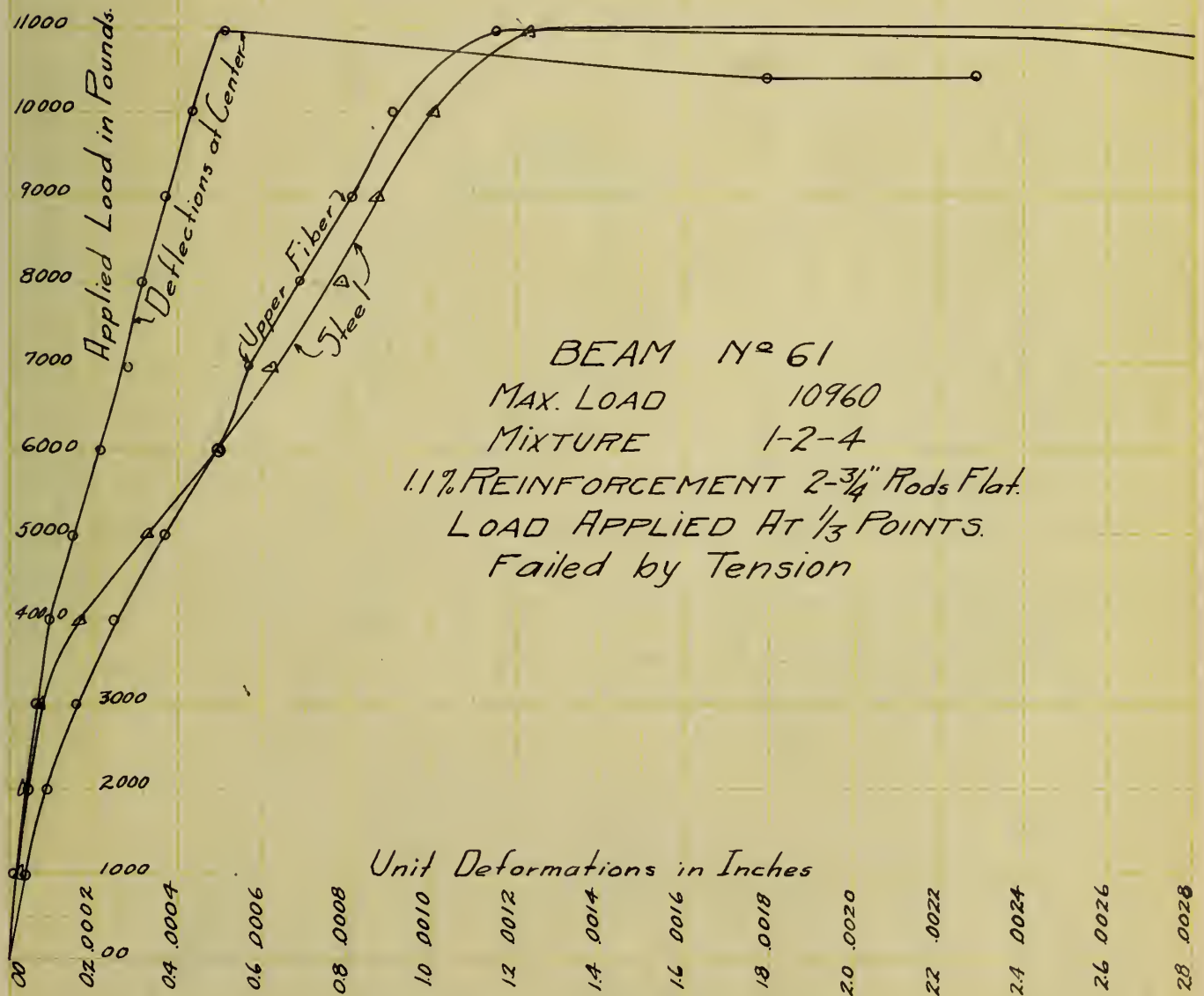




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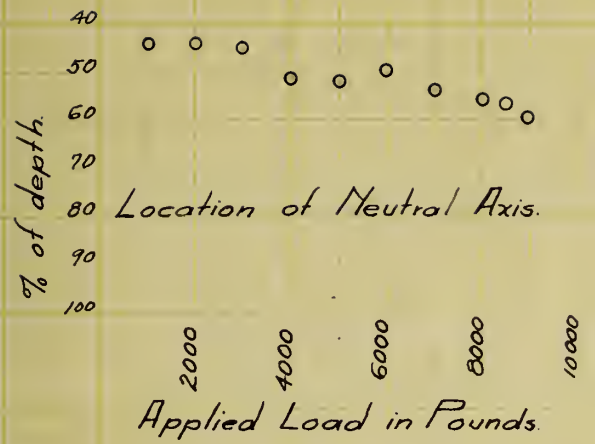
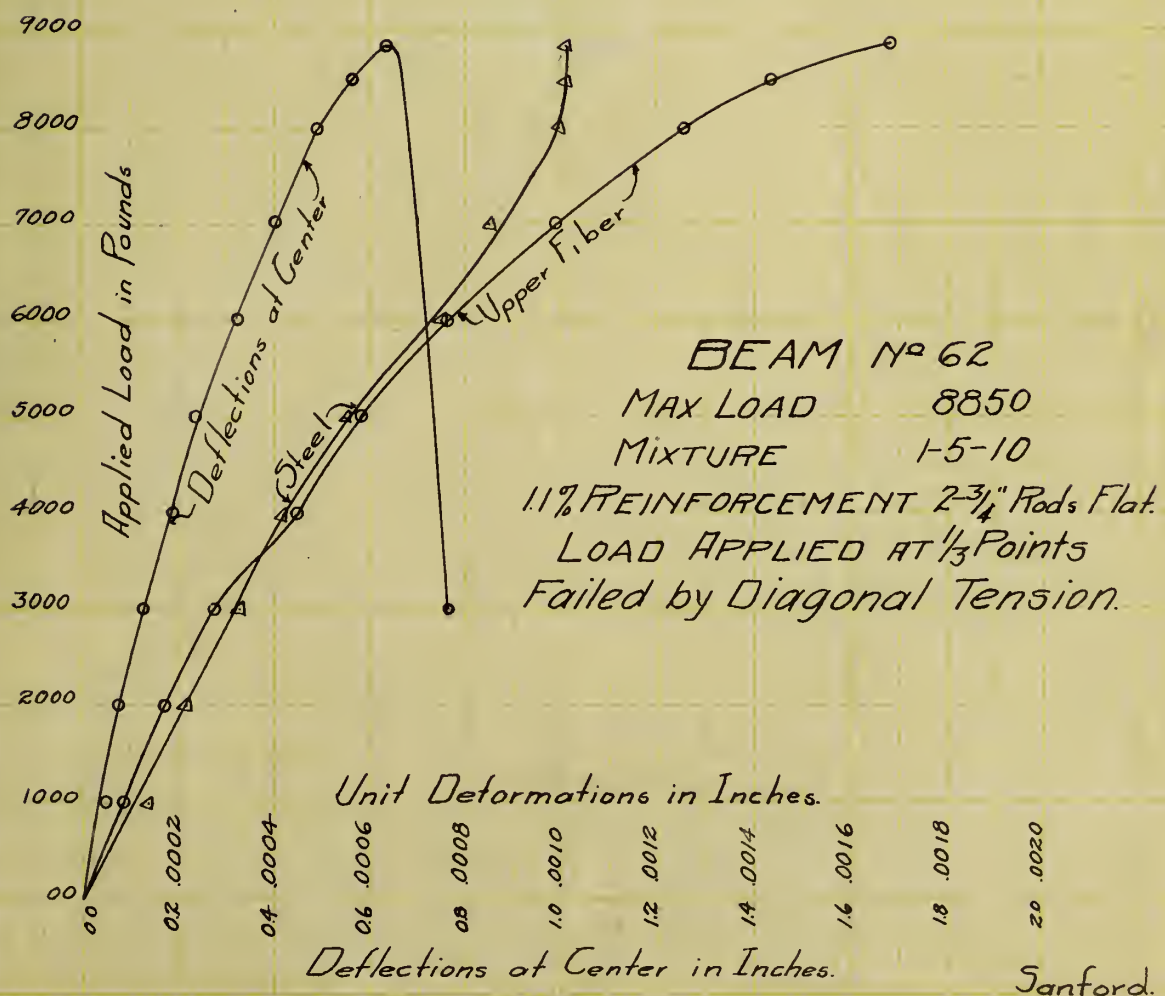
PLATE 5




BEAM Nº 62
MAX LOAD 8850
MIXTURE 1-5-10
1.11% REINFORCEMENT 2-3/4" Rods Flat.
LOAD APPLIED AT 1/3 Points
Failed by Diagonal Tension.

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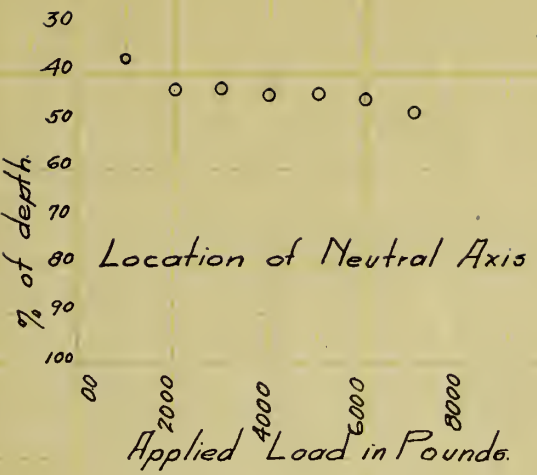
PLATE 6




# BEAM Nº63

MAX. LOAD 7360

MIXTURE 1-5-10

1.1% REINFORCEMENT 2-3/4" Rods Flat.

LOAD APPLIED AT 1/3 POINTS

Failed by Diagonal Tension.

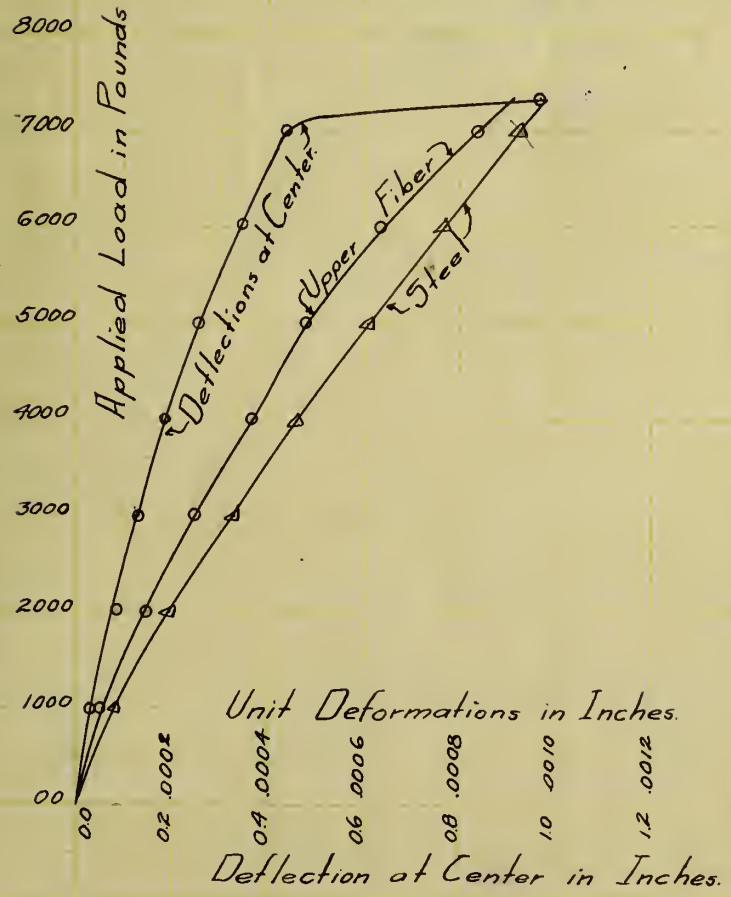



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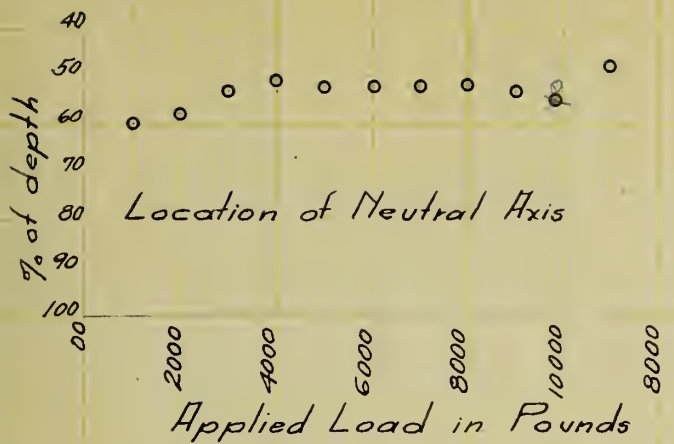
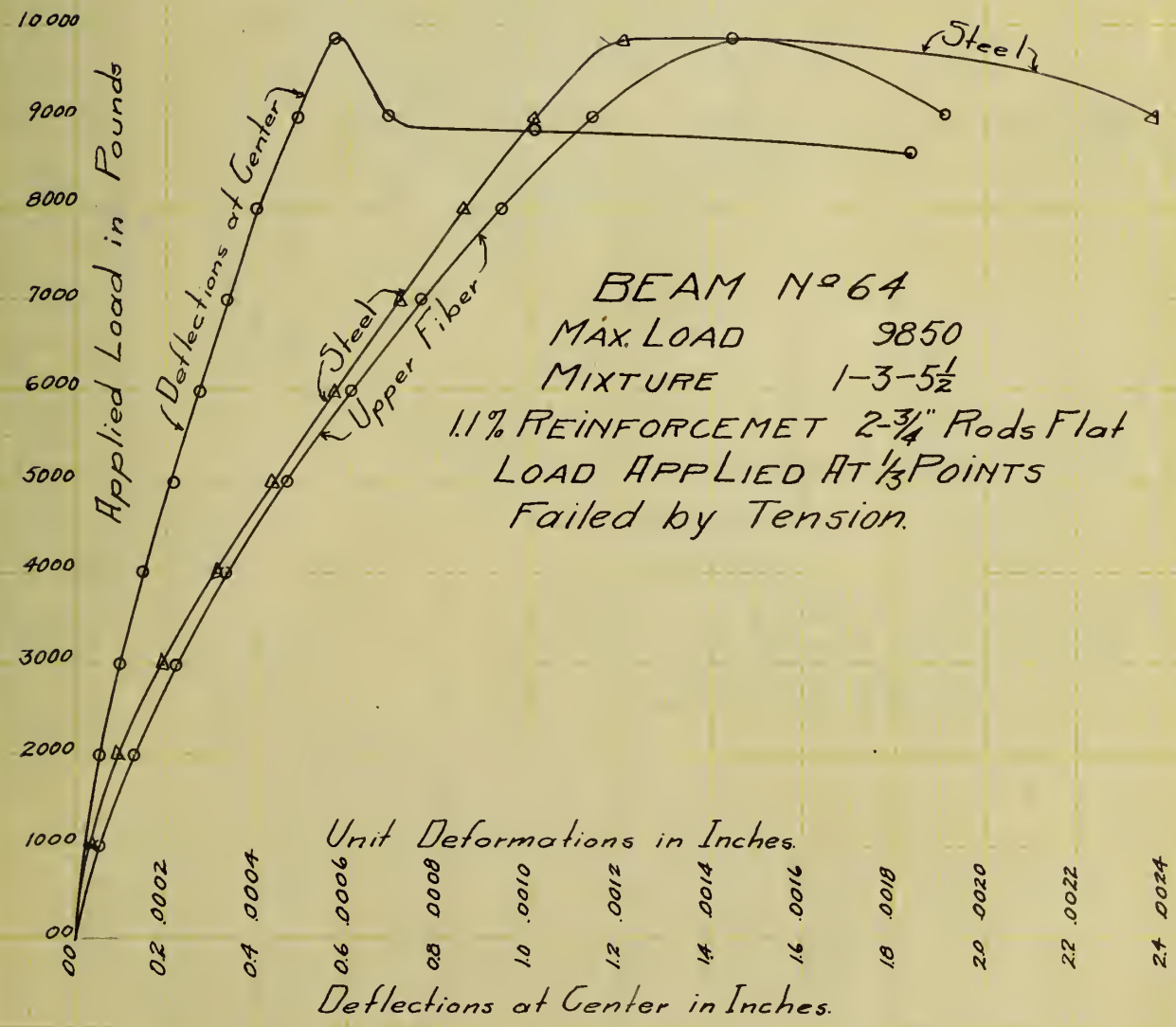
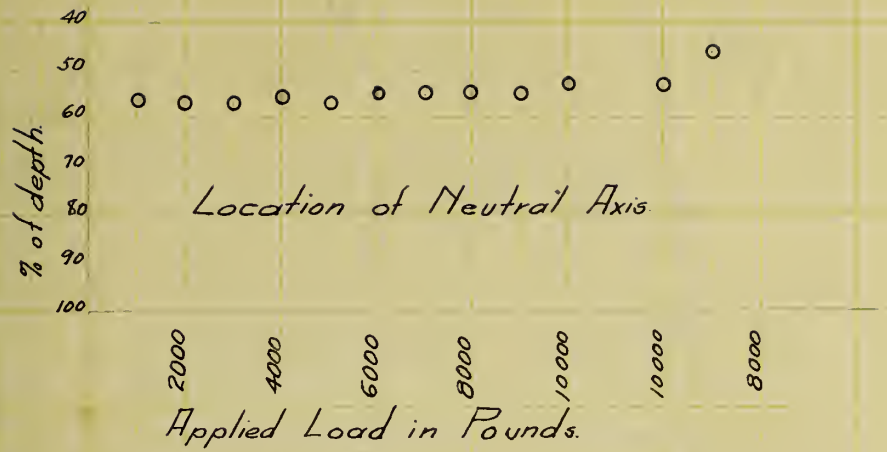
PLATE 7




Sanford.

PLATE 8


40
50
60
70
80
90
100
% of depth.
Location of Neutral Axis.
2000
4000
6000
8000
10000
10000
8000
Applied Load in Pounds.

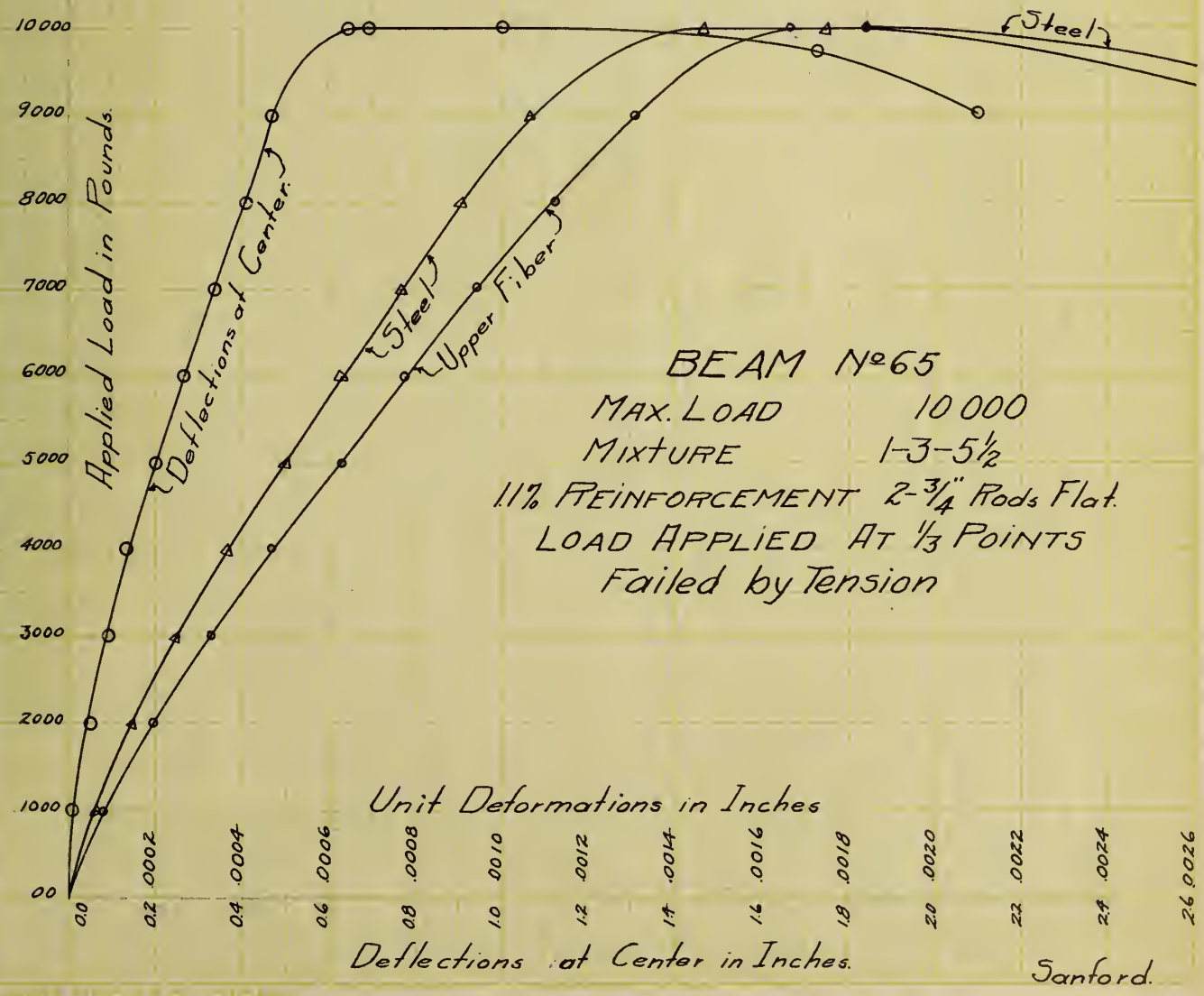
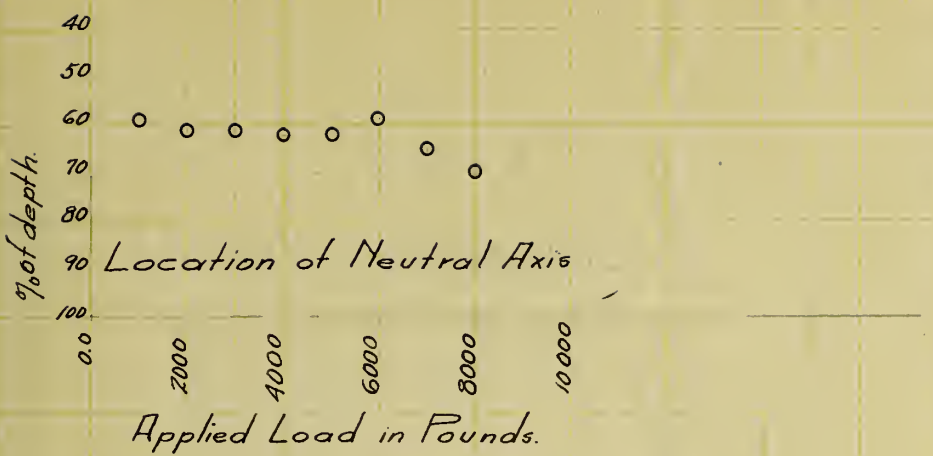

10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
00
Applied Load in Pounds.
Deflections at Center
Steel
Upper Fiber
Steel
BEAM No 65
MAX. LOAD 10 000
MIXTURE 1-3-5½
1.1% REINFORCEMENT 2-¾" Rods Flat.
LOAD APPLIED AT ⅓ POINTS
Failed by Tension
Unit Deformations in Inches
0.0
.02 .0002
.04 .0004
.06 .0006
.08 .0008
.10 .0010
.12 .0012
.14 .0014
.16 .0016
.18 .0018
.20 .0020
.22 .0022
.24 .0024
.26 .0026
Deflections at Center in Inches.
Sanford.

PLATE 9




# BEAM Nº 66

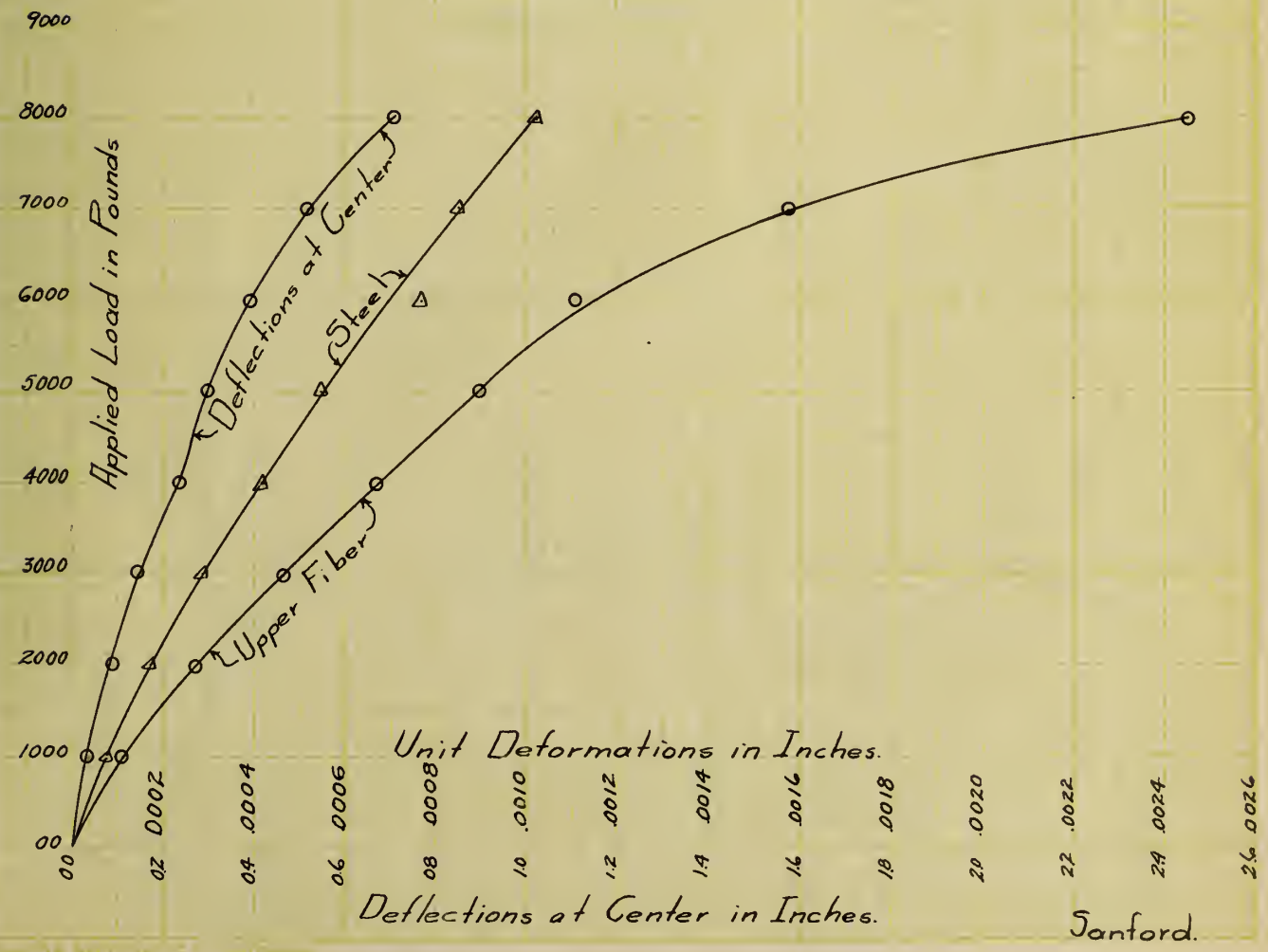
MAX LOAD 8000

MIXTURE 1-5-10

1.25% REINFORCEMENT 4-½" Johnson Bars Flat

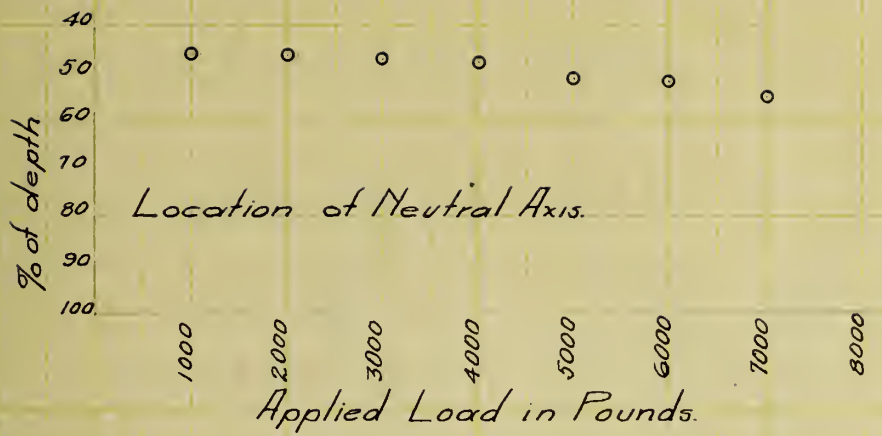
LOAD APPLIED AT ⅓ POINTS.

Failed by Diagonal Tension




Sanford.

PLATE 10




# BEAM Nº 67

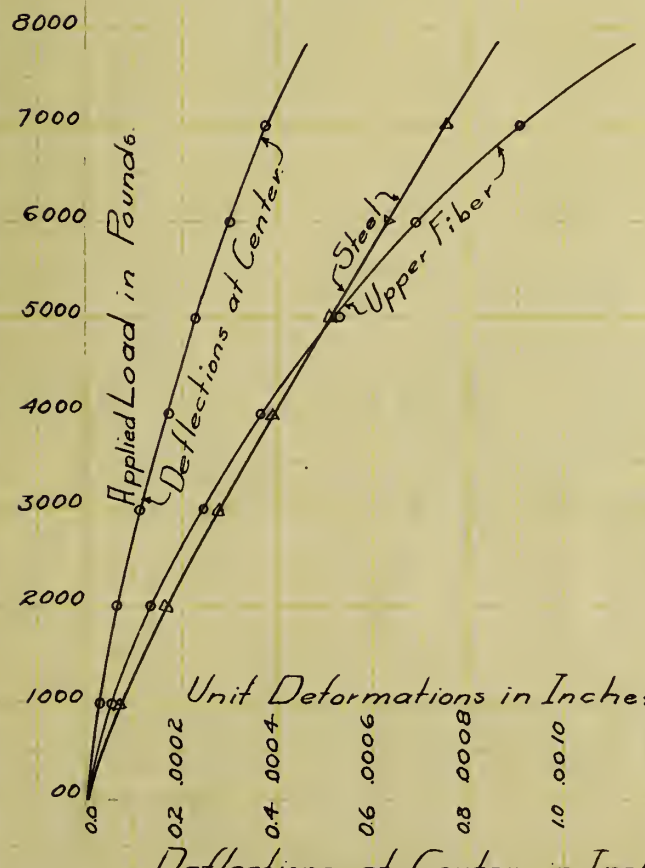
MAX. LOAD 7850

MIXTURE 1-5-10

1.25% REINFORCEMENT 4-½" Johnson Bars Flat.

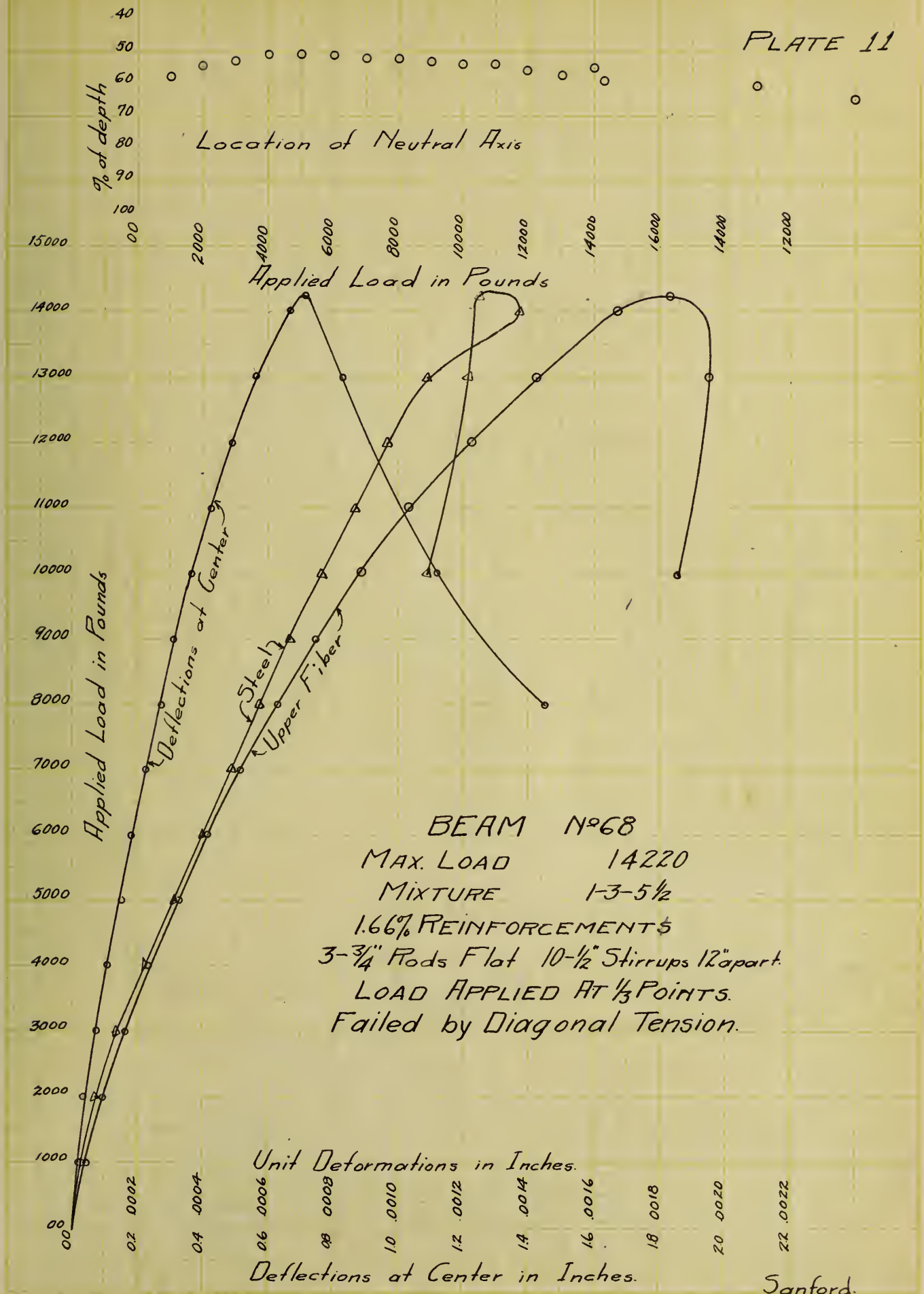
LOAD APPLIED AT ⅓ POINTS.

Failed by Diagonal Tension.

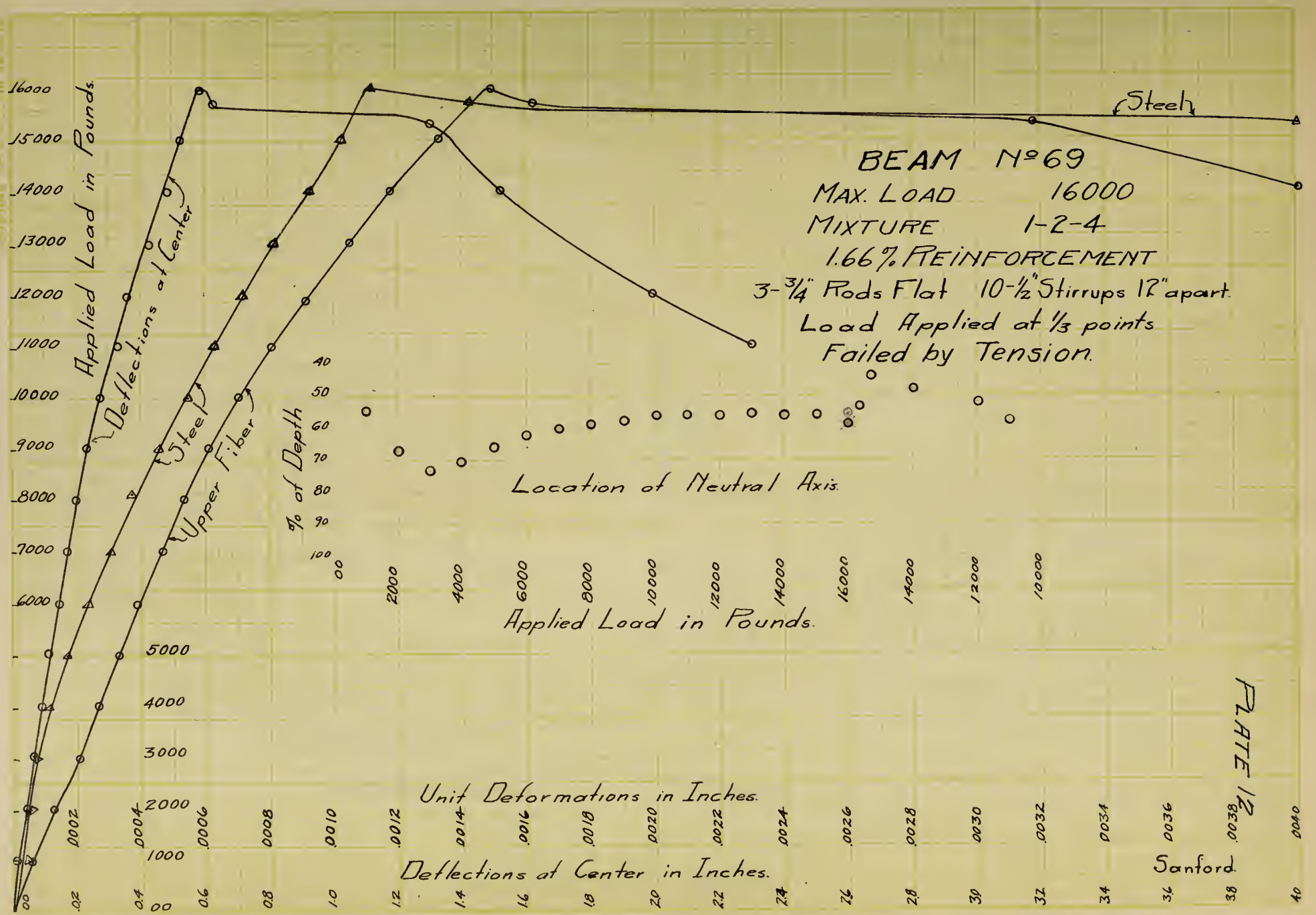



Sanford.

PLATE 11




Sanford.


BEAM Nº 69
MAX. LOAD 16000
MIXTURE 1-2-4
1.66% REINFORCEMENT
3-3/4" Rods Flat 10-½" Stirrups 12" apart.
Load Applied at ⅓ points
Failed by Tension.
Steel
Deflections at Center
Steel
Upper Fiber
Applied Load in Pounds.
% of Depth
Location of Neutral Axis.
Applied Load in Pounds.
Unit Deformations in Inches.
Deflections at Center in Inches.
PLATE 12
Sanford

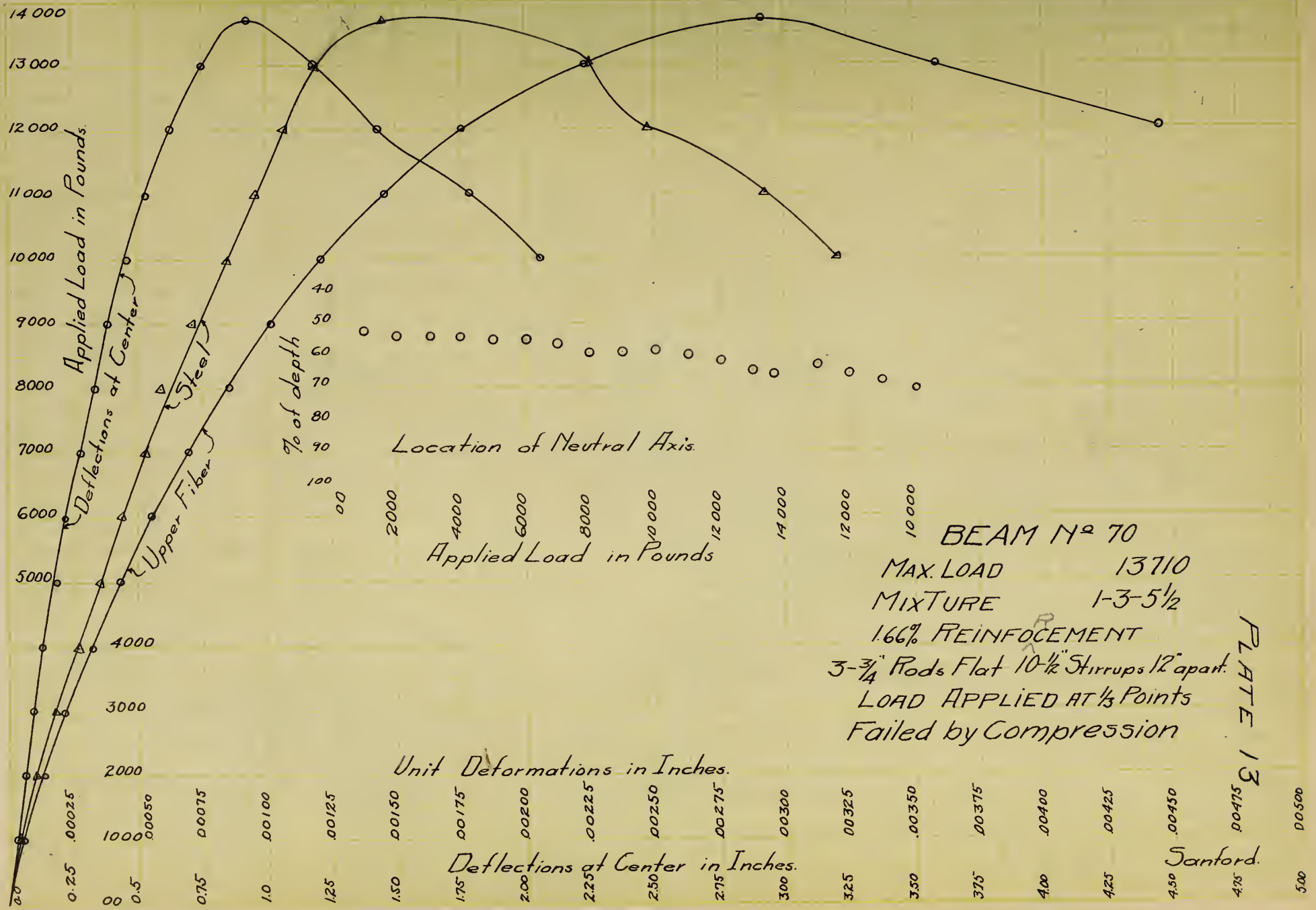
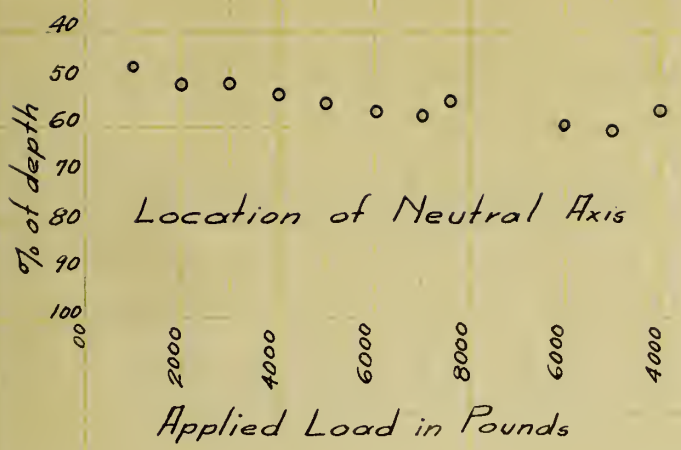

Applied Load in Pounds.
14 000
13 000
12 000
11 000
10 000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Deflections at Center
Steel
Upper Fiber
% of depth
00
10
20
30
40
50
60
70
80
90
100
Location of Neutral Axis
2000
4000
6000
8000
10 000
12 000
14 000
12 000
10 000
Applied Load in Pounds
BEAM Nº 70
MAX. LOAD 13710
MIXTURE 1-3-5½
1.66% REINFOCEMENT
3-¾" Rods Flat 10-½" Stirrups 12" apart.
LOAD APPLIED AT ⅓ Points
Failed by Compression
Unit Deformations in Inches.
.00025
.00050
.00075
.00100
.00125
.00150
.00175
.00200
.00225
.00250
.00275
.00300
.00325
.00350
.00375
.00400
.00425
.00450
.00475
.00500
Deflections at Center in Inches.
0.25
0.5
0.75
1.0
1.25
1.50
1.75
2.00
2.25
2.50
2.75
3.00
3.25
3.50
3.75
4.00
4.25
4.50
4.75
5.00
Sanford.

PLATE 13

PLATE 14




# BEAM Nº 71

MAX. LOAD 7600.

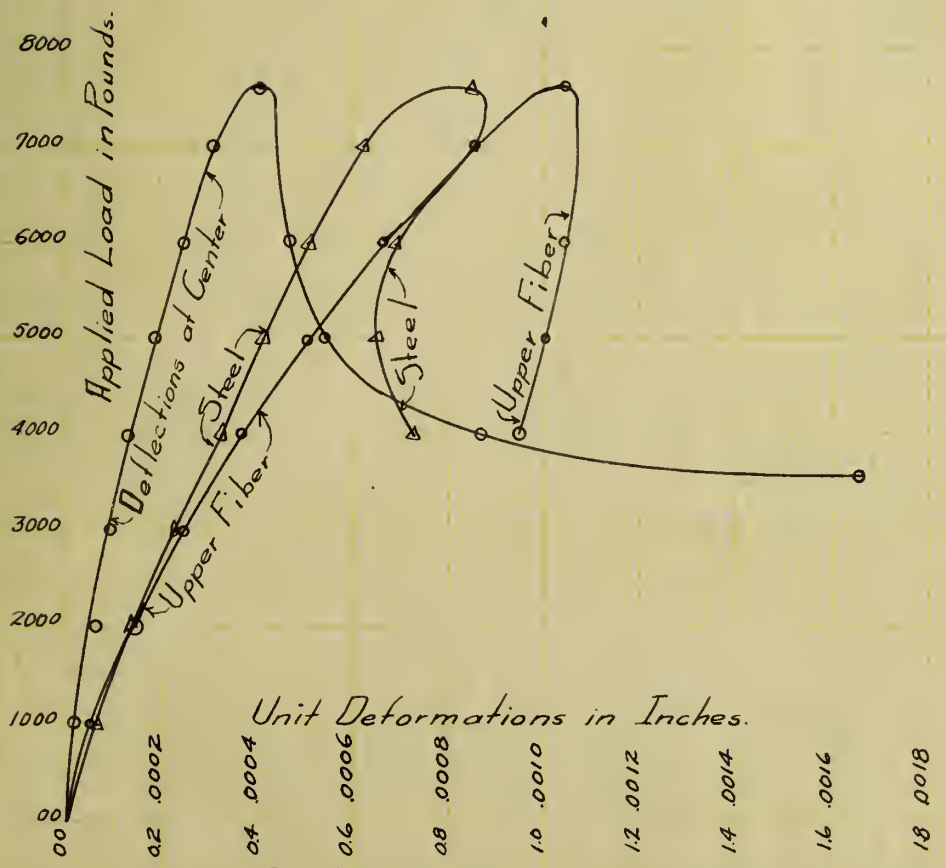
MIXTURE 1-5-10

1.66% REINFORCEMENT

3-3/4" Rods Flat 10-½" Stirrups 12" apart.

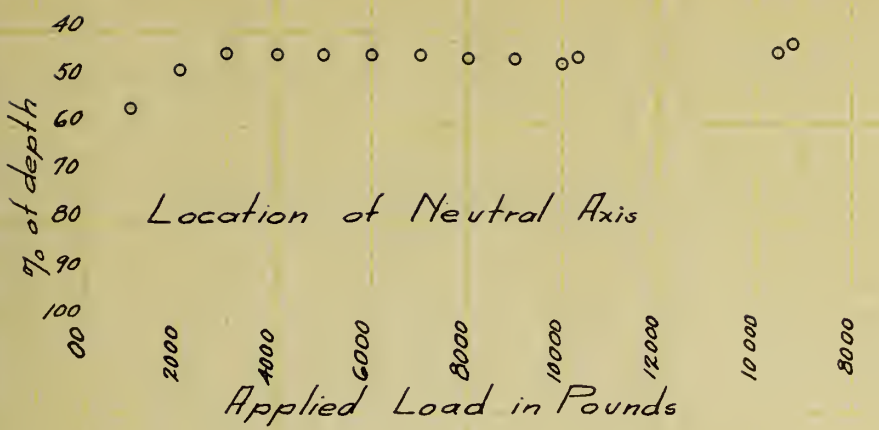
LOAD APPLIED AT ⅓ POINTS

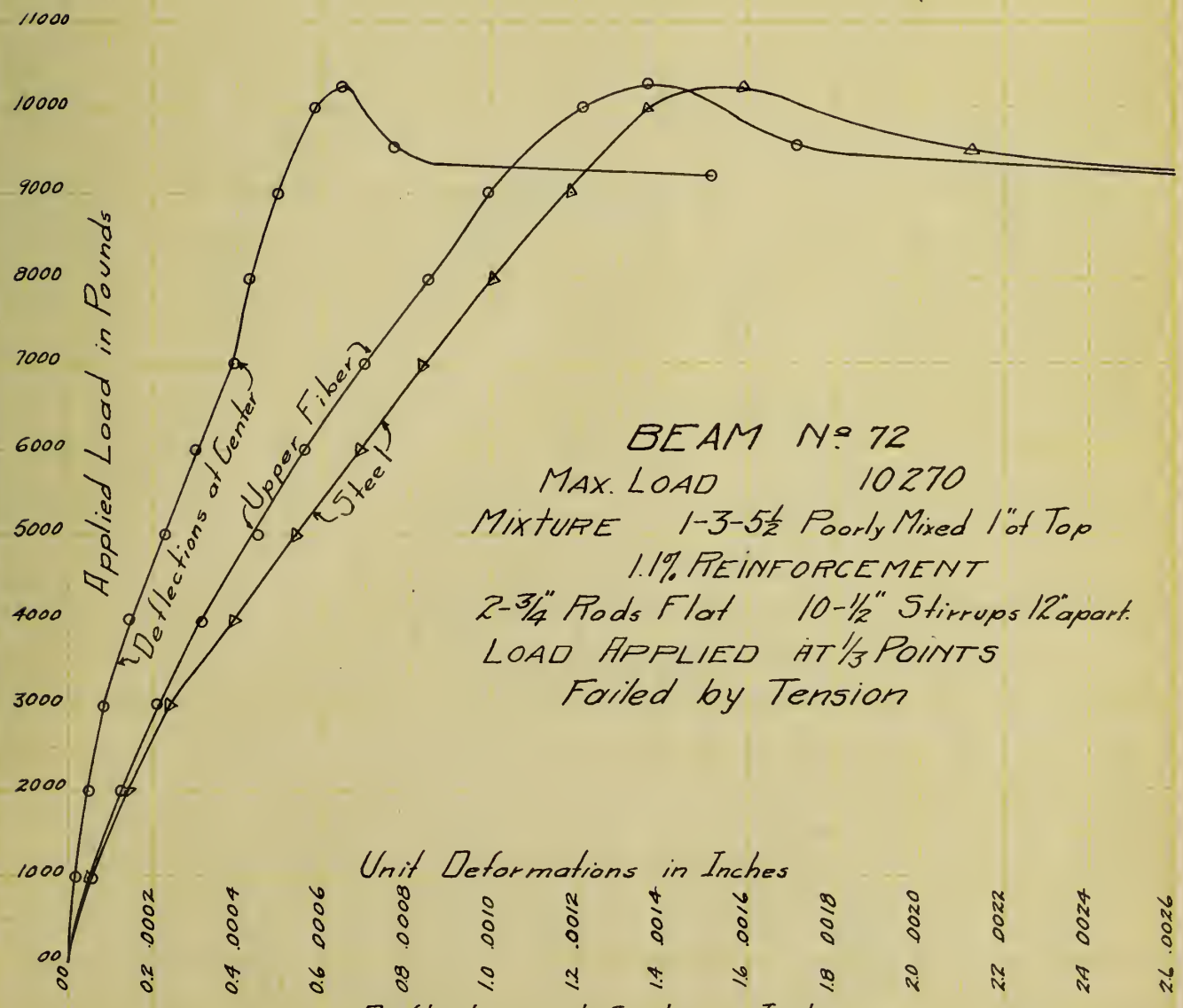
Failed by Diagonal Tension.




Sanford.

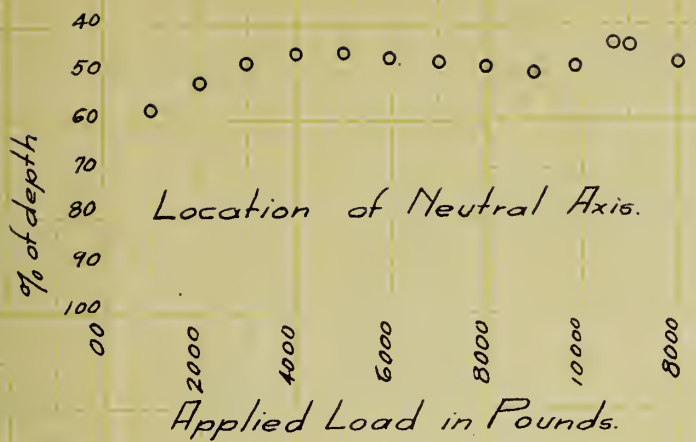
PLATE 15

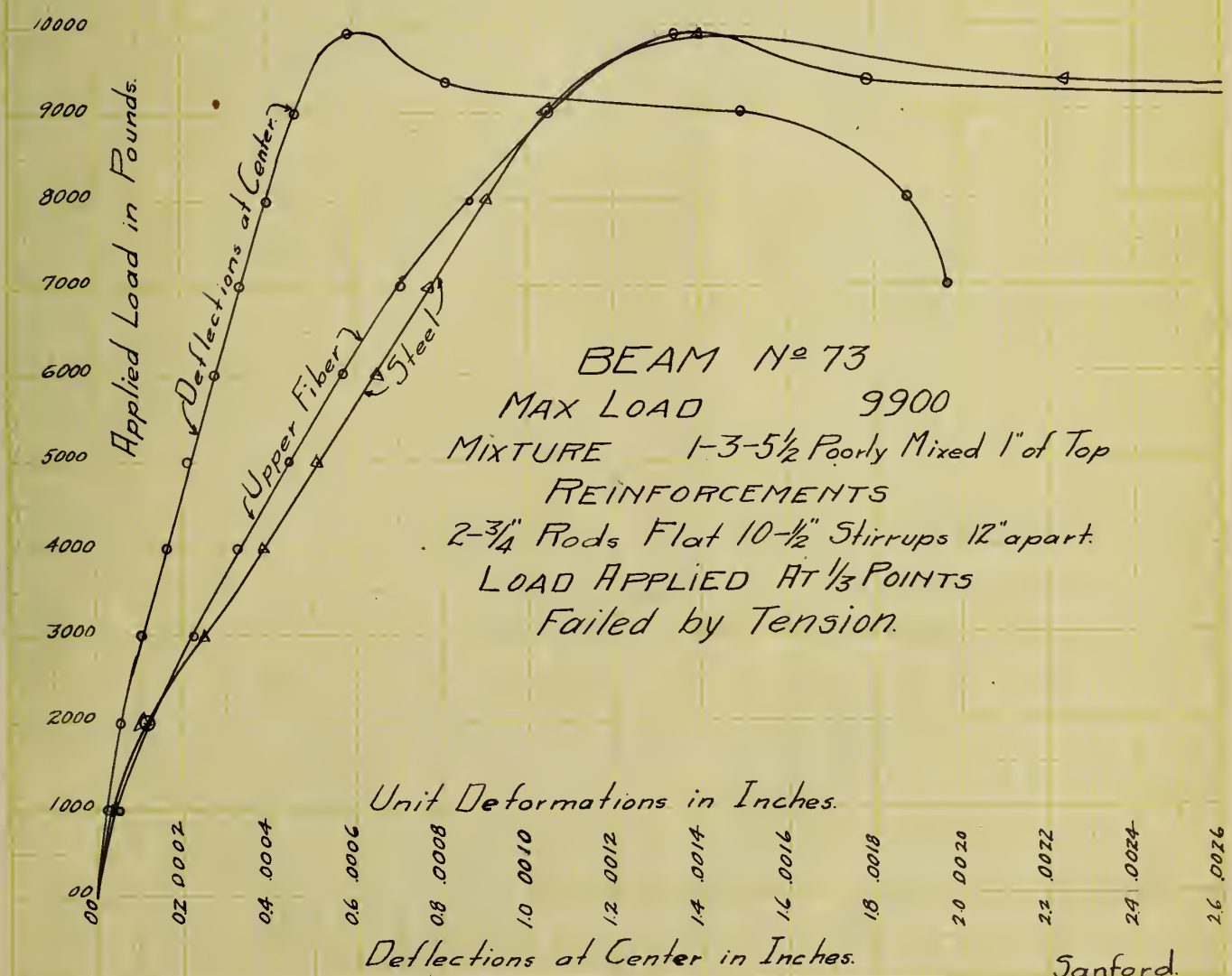



Sanford

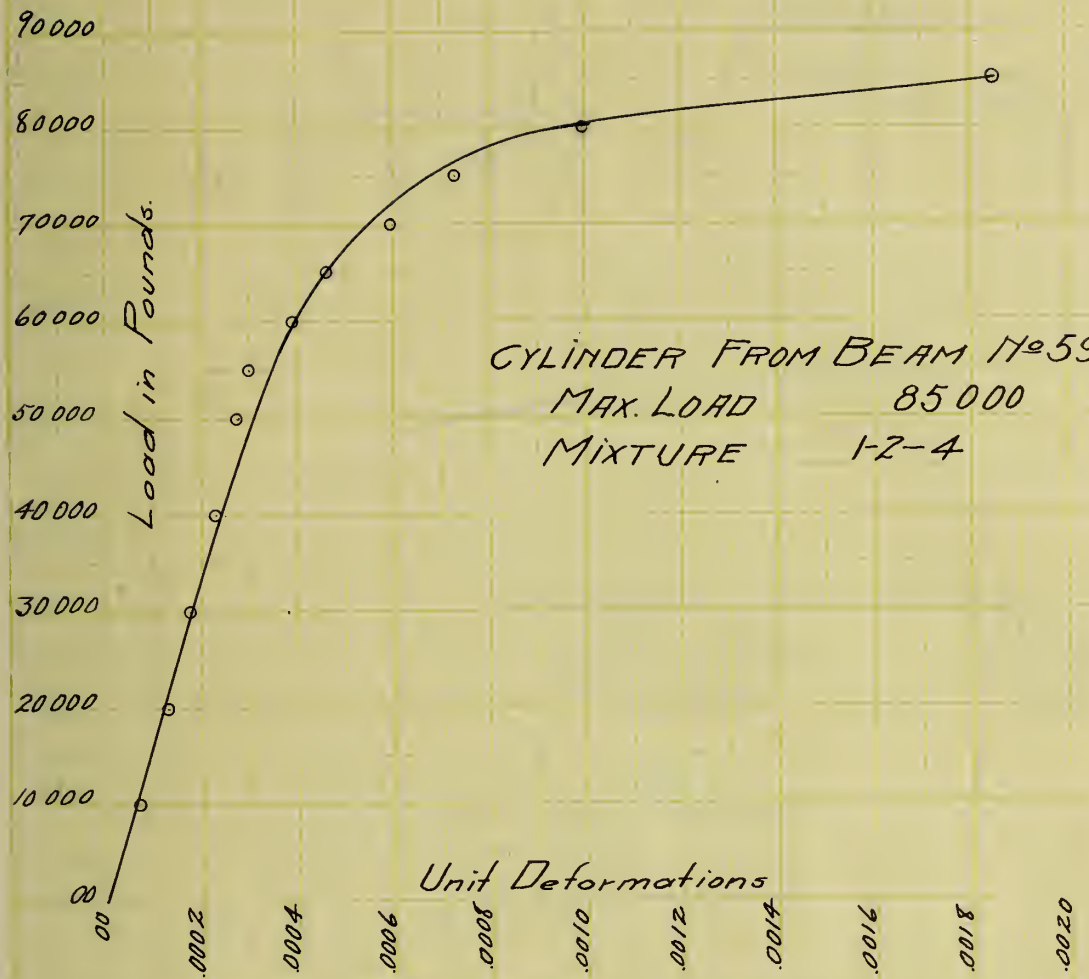
PLATE 16



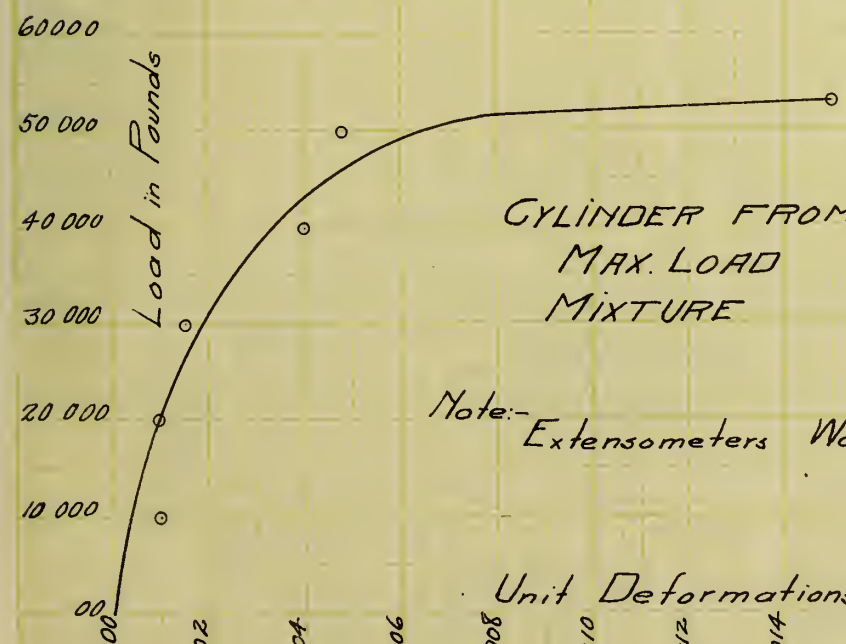




Sanford.

PLATE Nº 17




CYLINDER FROM BEAM Nº 59
MAX. LOAD 85000
MIXTURE 1-2-4




CYLINDER FROM BEAM Nº 58
MAX. LOAD 53000
MIXTURE 1-3-5½

Note:- Extensometers Worked Poorly.

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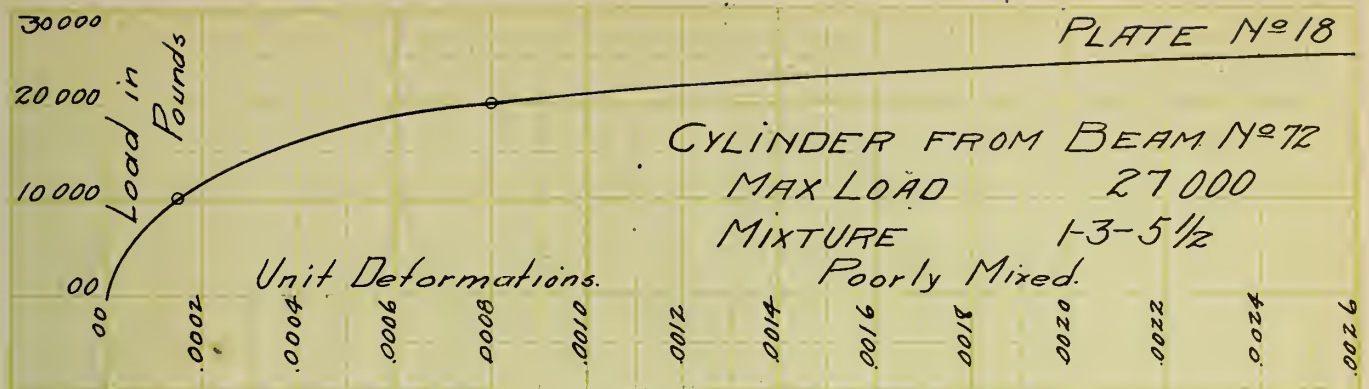
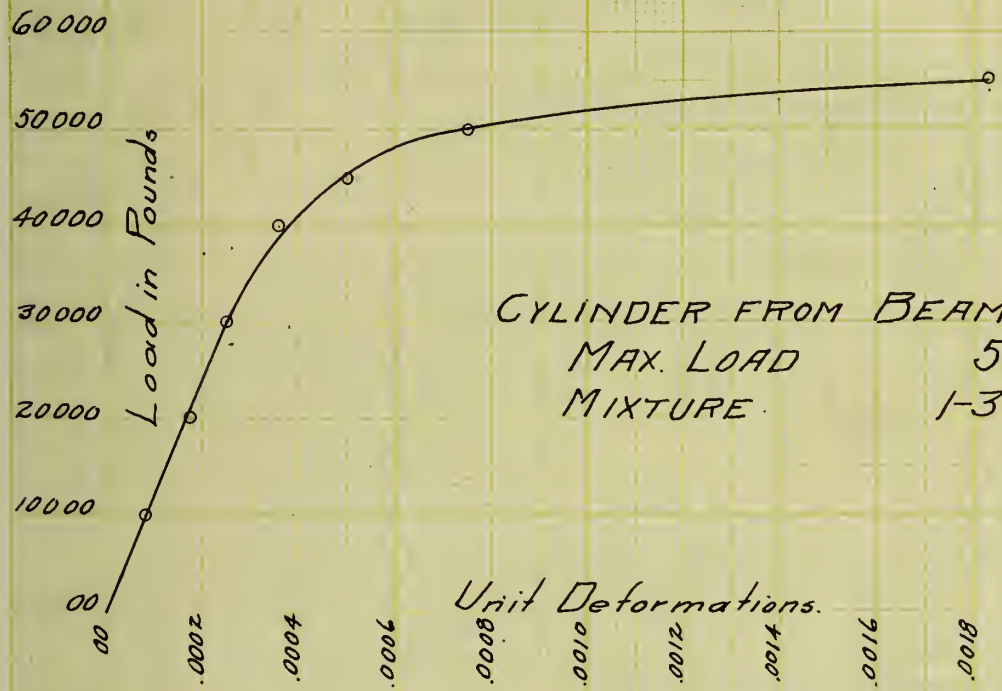
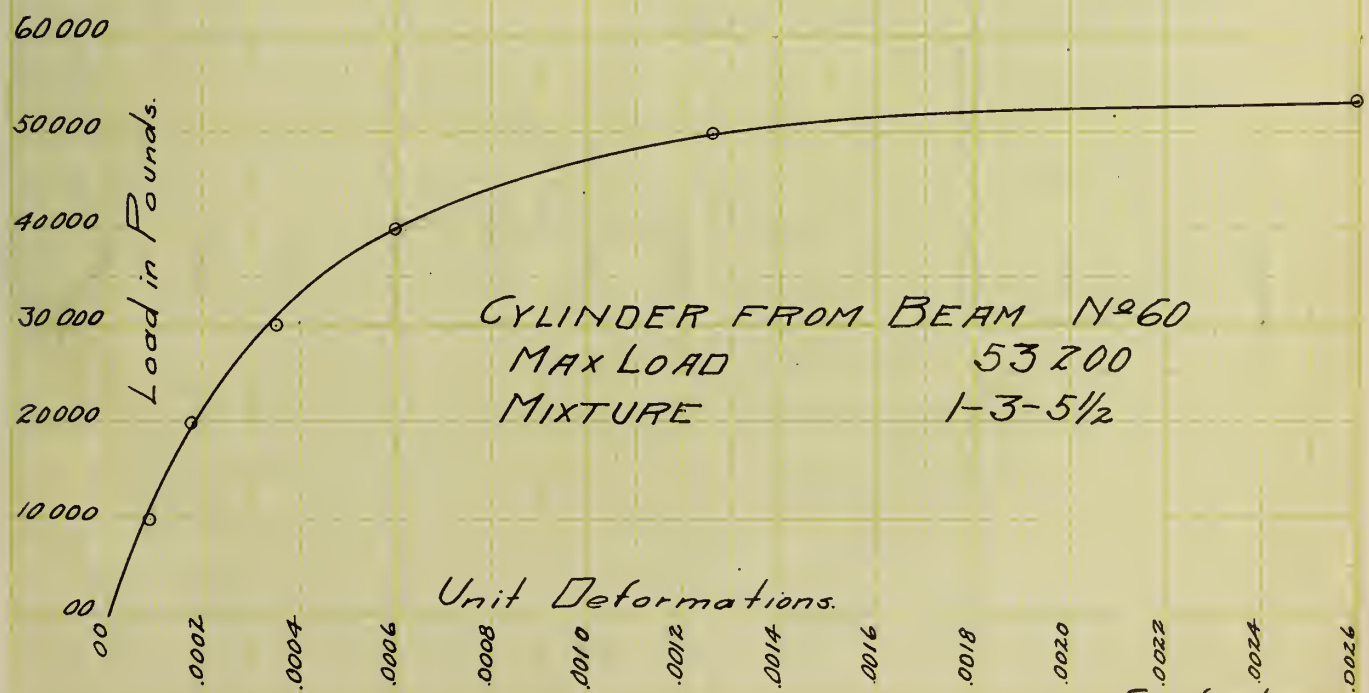
PLATE Nº 18




CYLINDER FROM BEAM Nº 72
MAX LOAD 27 000
MIXTURE 1-3-5½
Poorly Mixed.




CYLINDER FROM BEAM Nº 70
MAX. LOAD 55 000
MIXTURE 1-3-5½




CYLINDER FROM BEAM Nº 60
MAX LOAD 53 200
MIXTURE 1-3-5½

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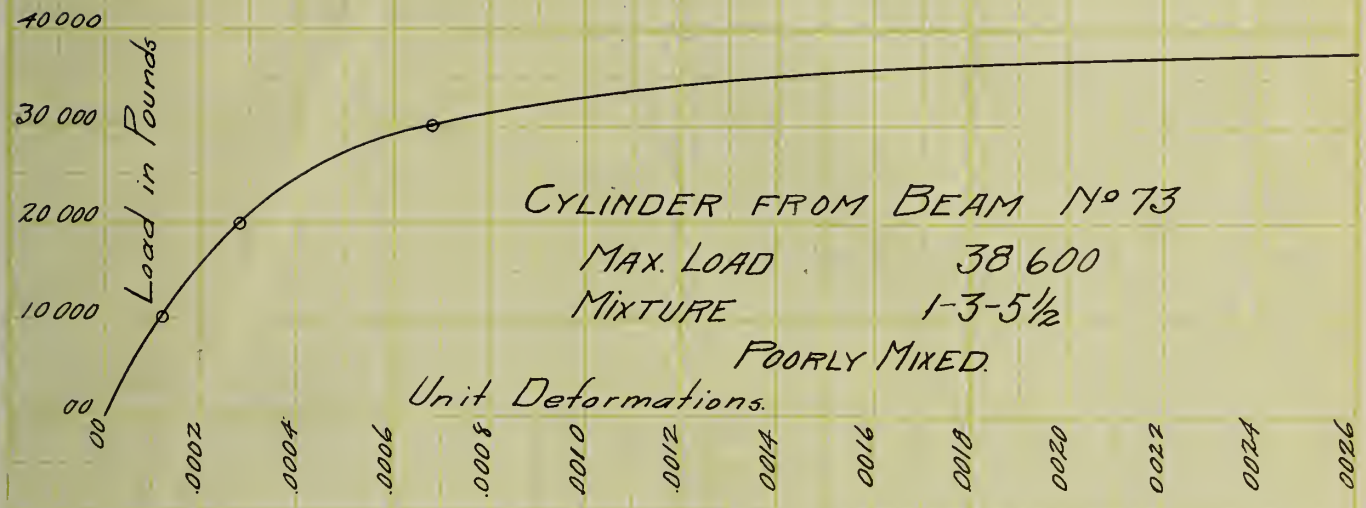
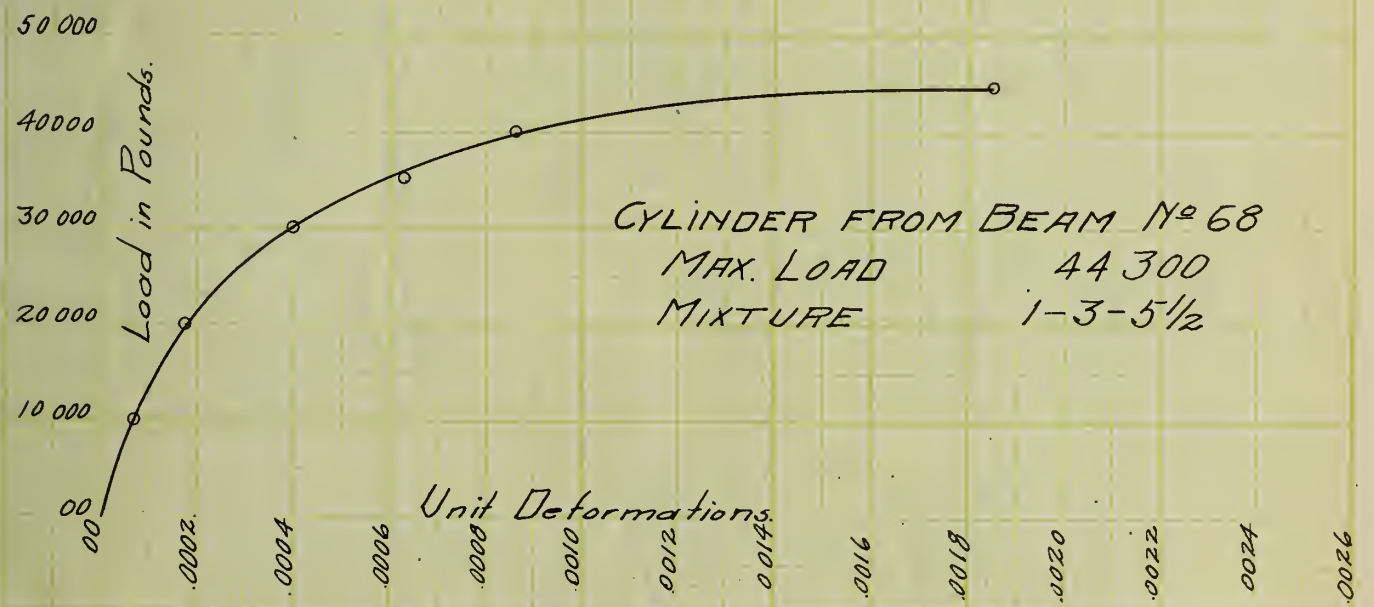
PLATE Nº 19




CYLINDER FROM BEAM Nº 73
MAX. LOAD 38 600
MIXTURE 1-3-5½
POORLY MIXED.




CYLINDER FROM BEAM Nº 68
MAX. LOAD 44 300
MIXTURE 1-3-5½

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